kosmos®
electronic X 3000/X 4000

Franckh'sche Verlagshandlung
Stuttgart

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kosmos®
electronic X 3000/X 4000

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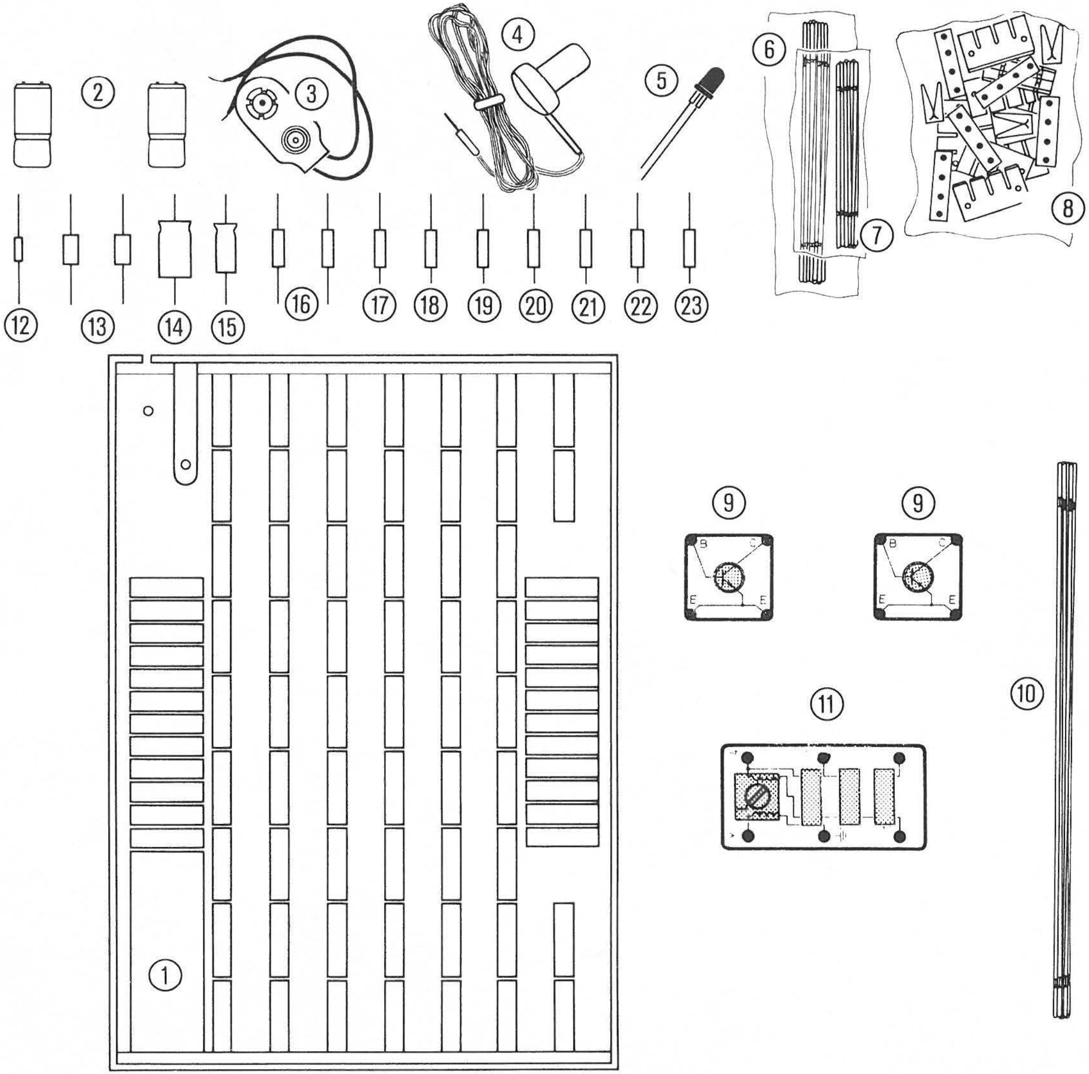
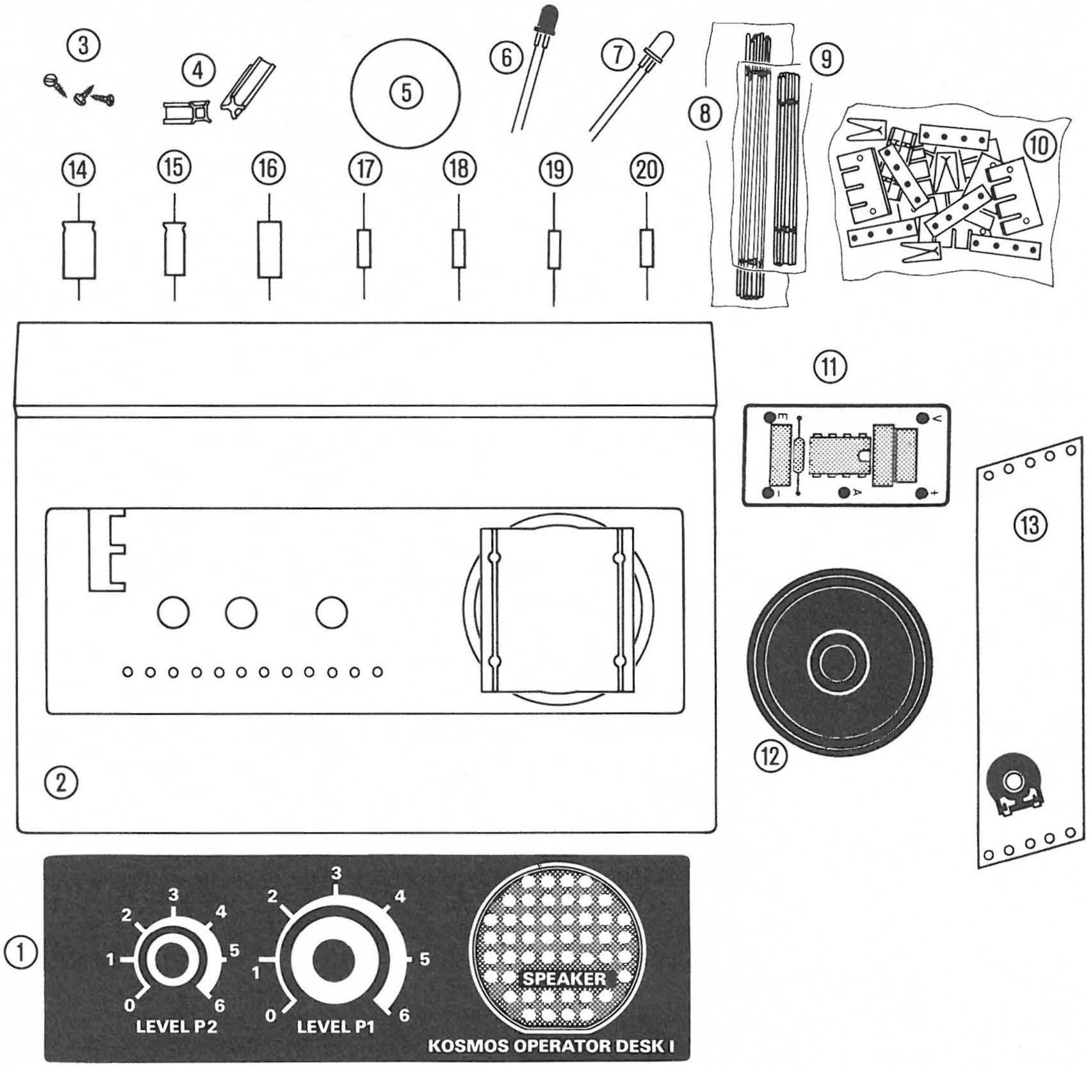
Stuttgart

Kosmos electronic X 3000 Ⓘ



Part I	**Order No.**
1. Plug board	60-7010.7
2. Two contact makers	60-0036.7
3. Battery clip with pin plugs	60-4210.6
4. Earphone	60-4205.6
5. Light-emitting diode (LED)	60-0205.8
6. Packet of long wire connectors	60-0029.2
7. Packet of short wire connectors	60-0028.2
8. Packet of contact clips	60-0061.2
9. Two npn transistor modules each	60-4300.6
10. Bundle of wire pieces	60-4110.2
11. AM module	60-4301.6
12. Germanium diode	60-0203.8
13. Two capacitors 6.8 nF each	60-0326.8
14. Electrolytic capacitor 100 µF	60-0334.8
15. Electrolytic capacitor 10 µF	60-0335.8
16. Two resistors 470 Ω each	60-0435.8
17. Resistor 1 kΩ	60-0430.8
18. Resistor 5.6 kΩ	60-0405.8
19. Resistor 15 kΩ	60-0432.8
20. Resistor 33 kΩ	60-0413.8
21. Resistor 100 kΩ	60-0425.8
22. Resistor 220 kΩ	60-0434.8
23. Resistor 680 kΩ	60-0442.8

Kosmos electronic X 3000 (II)



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LEVEL P1
SPEAKER
KOSMOS OPERATOR DESK I
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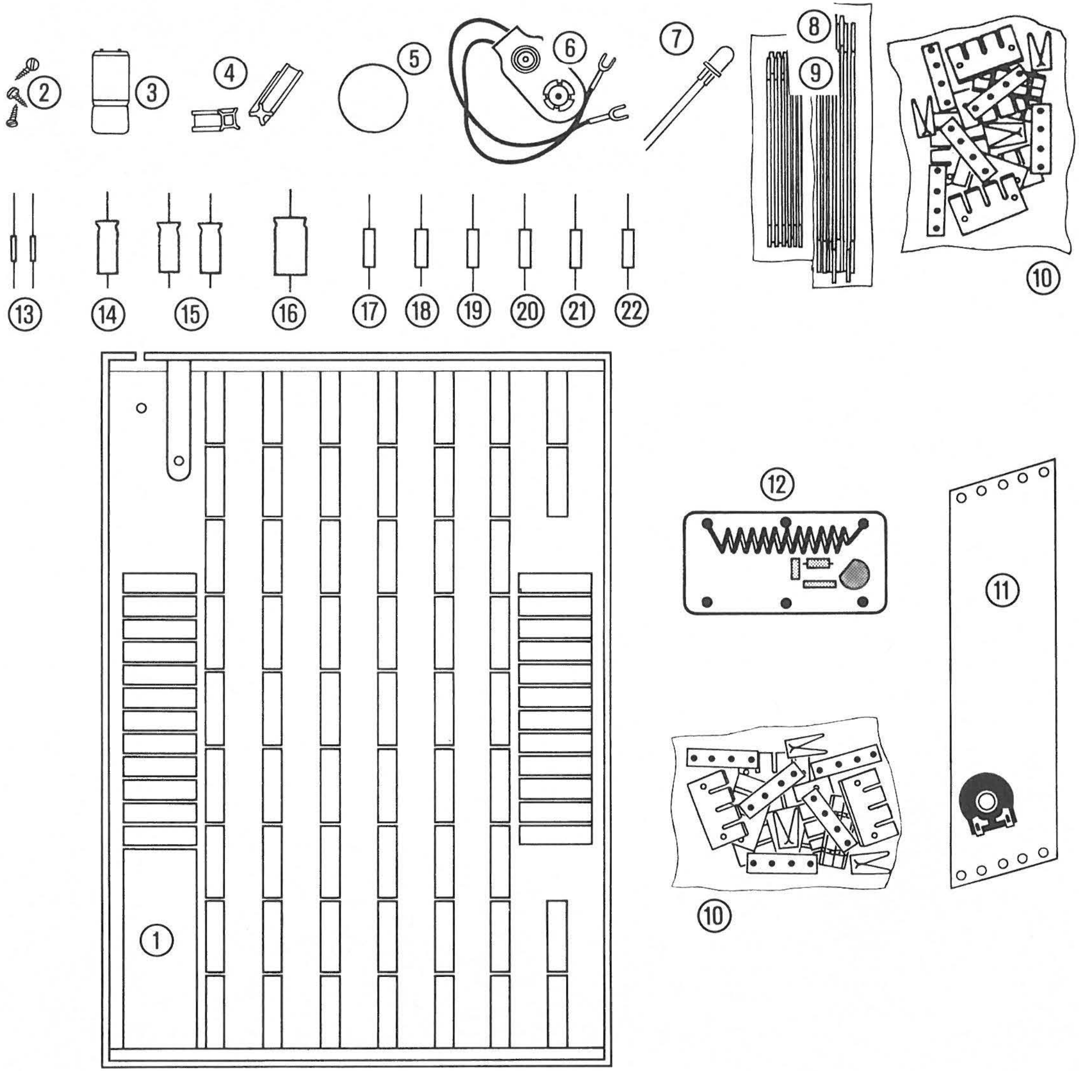
Part II	Order No.
1. Decorative cover DESK I	60-7001.6
2. Operator desk	60-7015.7
3. Three self-tapping screws each .	60-2018.8
4. Two connecting rods each	60-8372.7
5. Adjustment knob, large	60-8371.7
6. Light-emitting diode (LED)	60-0205.8
7. Phototransistor (T_F)	60-0211.8
8. Packet long wire connectors . . .	60-0029.2
9. Packet short wire connectors . .	60-0028.2
10. Packet contact clips	60-0061.2
11. Amplifier module	60-4303.6
12. Loudspeaker	60-4201.6
13. Potentiometer module P1	60-4302.6
14. Electrolytic capacitor 1 µF	60-0305.8
15. Electrolytic capacitor 10 µF . . .	60-0335.8
16. Capacitor 100 nF (0.1 µF)	60-0312.8
17. Resistor 10 Ω	60-0450.8
18. Resistor 100 Ω	60-0428.8
19. Resistor 3.3 kΩ	60-0437.8
20. Resistor 10 kΩ	60-0431.8

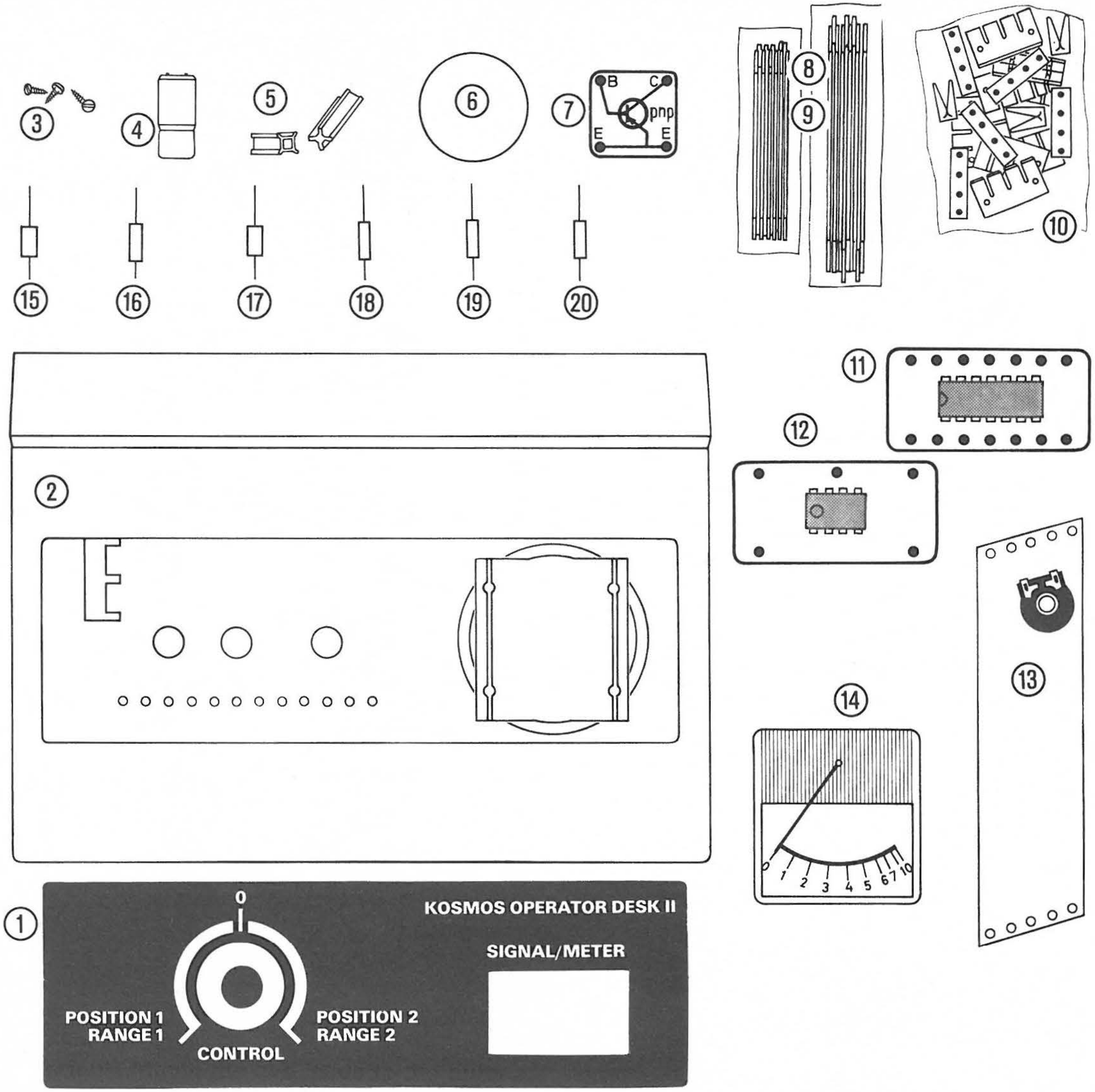
Kosmos electronic X 3000 (III)



PART III	Order No.
1. Plug board	60-7010.7
2. Three cheese-head self-tapping screws each	60-2018.0
3. Contact maker	60-0036.7
4. Two connecting rods each	60-8372.7
5. Adjustment knob, small	60-8373.7
6. Battery clip with screw connectors	60-4211.6
7. IF light-emitting diode	60-0201.8
8. Packet of long wire connectors	60-0029.2
9. Packet of short wire connectors	60-0028.2
10. Two packets of contact clips each	60-0061.2
11. Potentiometer module (P2)	60-4305.6
12. FM module	60-4304.6
13. Two Si diodes	60-0204.8
14. Electrolytic capacitor 10 μF	60-0335.8
15. Two electrolytic capacitors 100 μF	60-0334.8
16. Electrolytic capacitor 470 μF	60-0333.8
17. Capacitor 100 nF	60-0312.8
18. Resistor 150 Ω	60-0419.8
19. Resistor 1.5 kΩ	60-0444.8
20. Resistor 2.7 kΩ	60.0421.8
21. Resistor 10 kΩ	60-0431.8
22. Resistor 22 kΩ	60-0433.8

Kosmos electronic X 4000 Ⓘⓥ

Part IV	Order No.
1. Decorative plate DESK II	60-7002.6
2. Operator desk	60-7015.7
3. Three cheese-head self-tapping screws each	60-2018.8
4. Two connecting rods	60-8372.7
5. Contact maker	60-0036.7
6. Adjustment knob, large	60-8371.7
7. Transistor pnp	60-4306.6
8. Packet long wire connectors ...	60-0029.2
9. Packet short wire connectors ..	60-0028.2
10. Packet spring contacts	60-0061.2
11. Quad NAND gate	60-4309.6
12. Operational amplifier module ..	60-4308.6
13. Range-switch strip	60-4307.6
14. Meter	60-4219.6
15. Resistor 1.2 Ω	60-0401.8
16. Resistor 12 Ω	60-0412.8
17. Resistor 10 kΩ	60-0431.8
18. Resistor 39 kΩ	60-0423.8
19. Resistor 1 MΩ	60-0451.8
20. Resistor 1.5 MΩ	60-0471.8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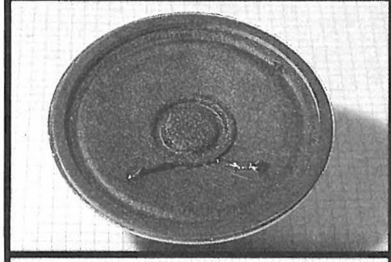
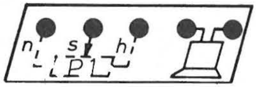
KOSMOS OPERATOR DESK II
SIGNAL/METER
POSITION 1
RANGE 1
CONTROL
POSITION 2
RANGE 2

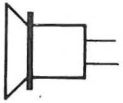
The components of Kosmos electronic X 3000

construction diagram

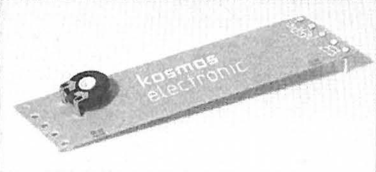
circuit diagram







loudspeaker


kosmos
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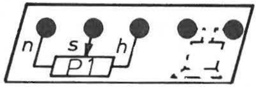
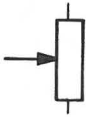
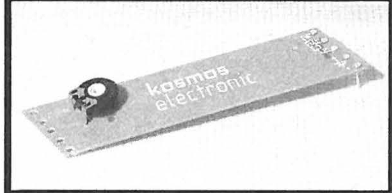




potentiometer P1


kosmos
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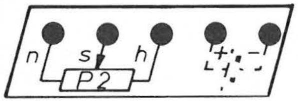
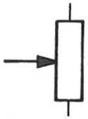
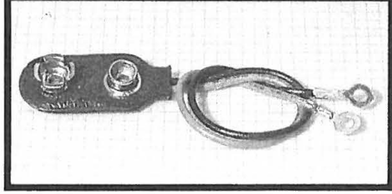
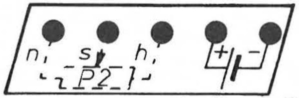
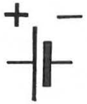




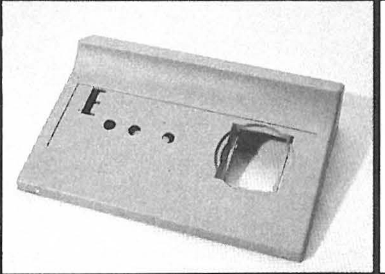
potentiometer P2



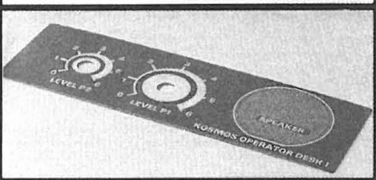




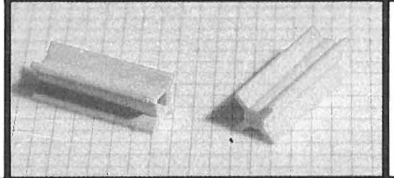
battery dip with scre connectors



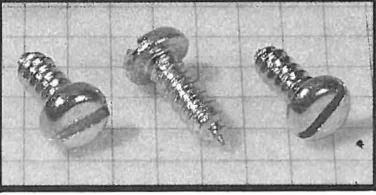
operator desk


LEVEL P2
LEVEL P1
SPEAKER
KOSMOS OPERATOR DESK I

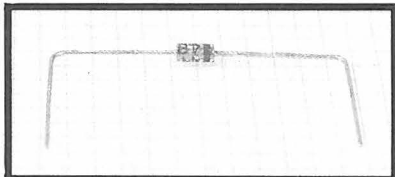
decorative cover DESK I



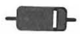
connecting rods



screws for potentiometer module

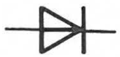


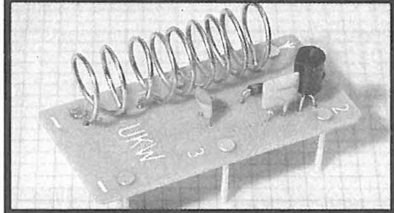
construction diagram

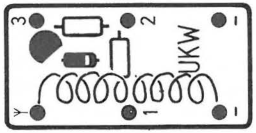


SI diode

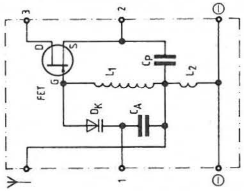
circuit diagram







FM module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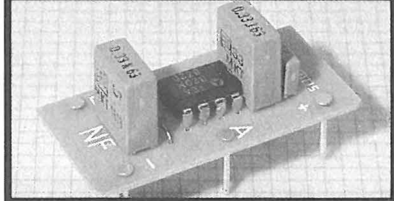
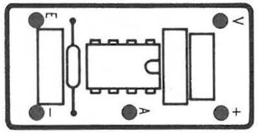
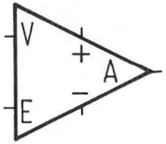
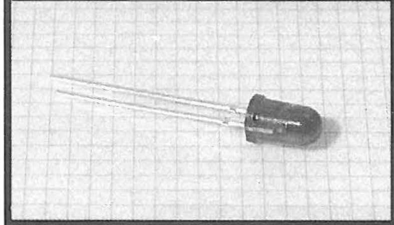
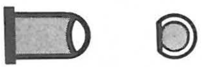


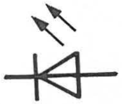




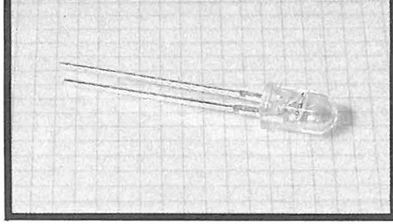
amplifier module

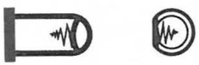


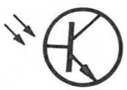




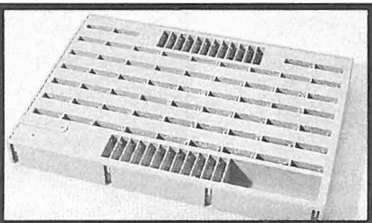
Beware!
Only use IF LED with
series resistor!



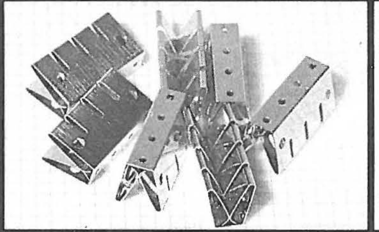




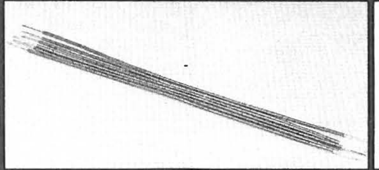
phototransistor



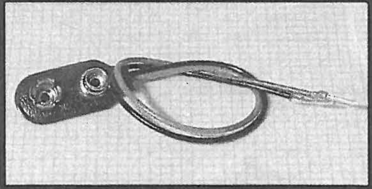
plug board



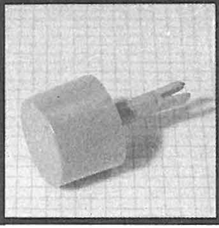
spring contacts

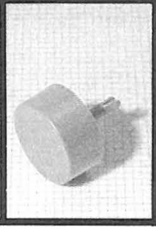


long pieces of wire

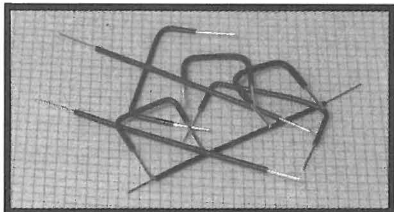


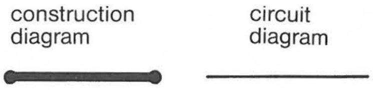
battery clip with pin contacts



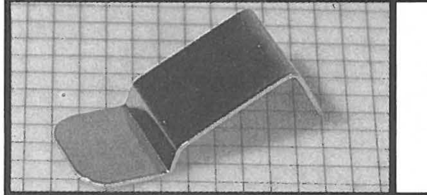


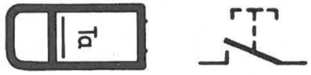
adjustment knobs



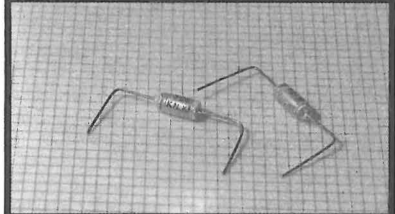

construction diagram
circuit diagram

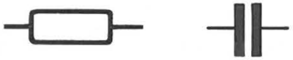
wire connector



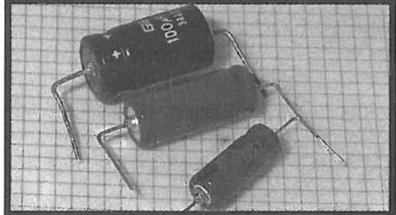


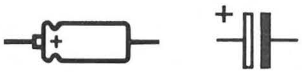
contact maker





capacitor





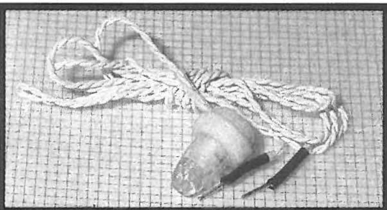
electrolytic capacitor

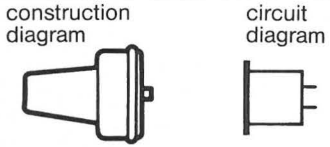
capacitors:

1 pF = 1 Picofarad
1 nF = 1 Nanofarad (1000 pF)
1 μF = 1 Mikrofarad (1000 nF)

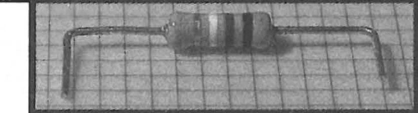
resistors:

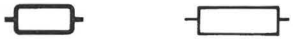
1 Ω = 1 Ohm
1 kΩ = 1 Kilo-Ohm (1000 Ω)
1 MΩ = 1 Meg-Ohm (1000 kΩ)



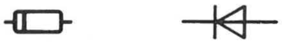

construction diagram
circuit diagram

earphone

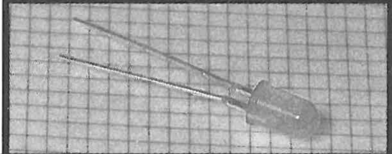


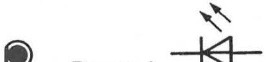


resistor

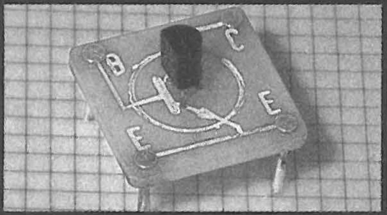


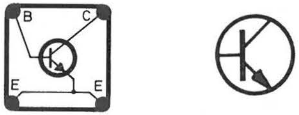
diode Ge



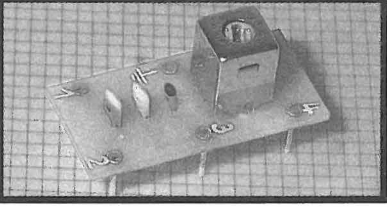


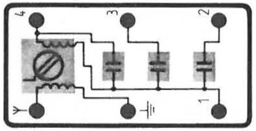
Beware!
Only use LED with
series resistor!





npn-transistor





AM module

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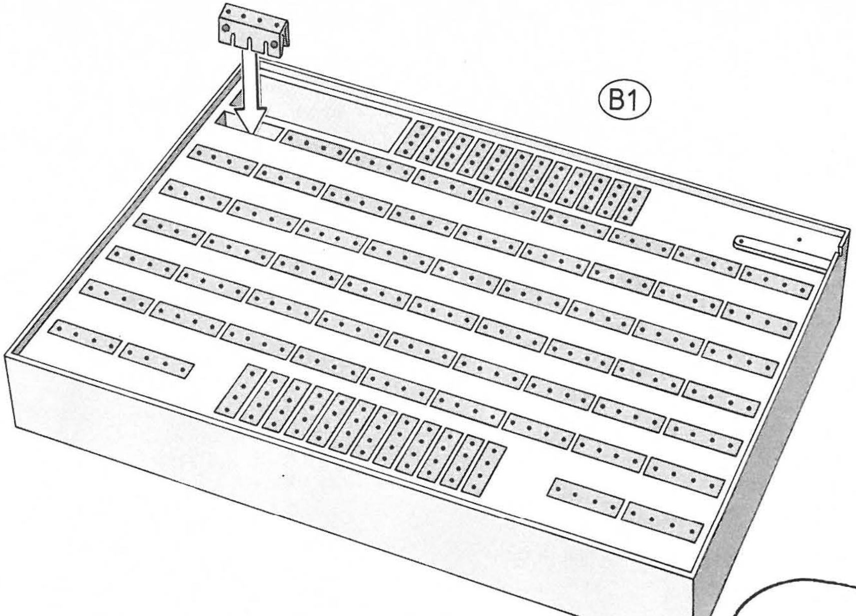
Part II 111

B. The KOSMOtronic plug system

Insertion of the contact clips

The electronic X 3000 experiment kit contains two plug boards, one in Part I and the other in Part II.

First equip both plug boards with the contact clips. Figure B1 shows how the contact clips are fitted into the plug board. The contact clips fit "audibly" into the recesses. **Note! One of the plug boards is completely equipped with contact clips, the second board is only partially equipped (see Fig. B2).**
Recesses 10, 20, 30, 40, 50, 60, 70 and 11 are left unoccupied. In addition the 12 recesses between contact clips 11 and 17 and the whole of the lower row remain vacent.
The electronic X 4000 kit contains contact clips for the unoccupied recesses. The plug boards on which you will later assemble the circuits are now ready. The plug boards and contact clips together make up the basic elements for the universal KOSMOtronic connecting system. The various components can be inserted directly or via modules into the contact clips. The contact clips thus establish electrical contact between the individual components and, at the same time, provide the necessary mechanical stability. Here is a tip: **always** insert the pins of the components and the wires **vertically** into the contact clip holes. The ends of the wires should never be bent, otherwise there is the danger that they will stick in the contact clips like "corkscrews" and damage them.



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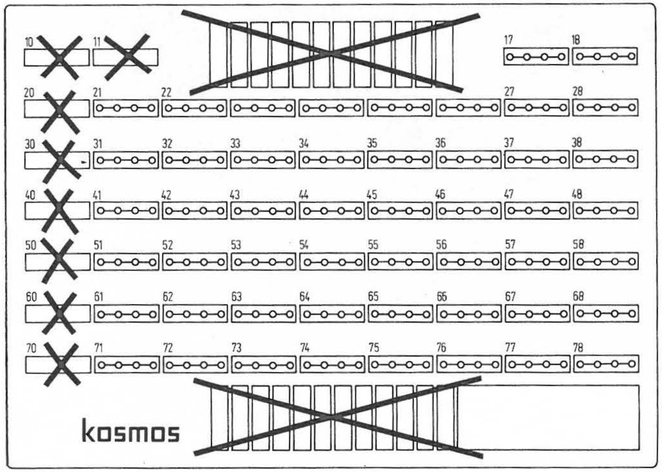
B2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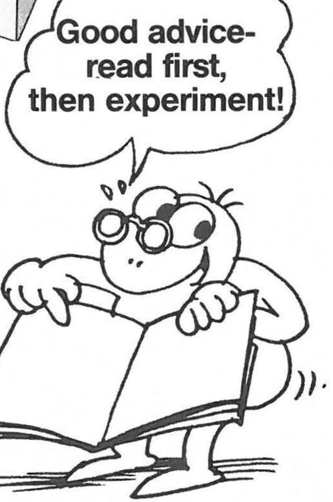
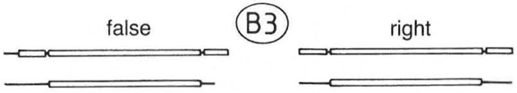
kosmos


Good advice-
read first,
then experiment!

Bending the wire connections

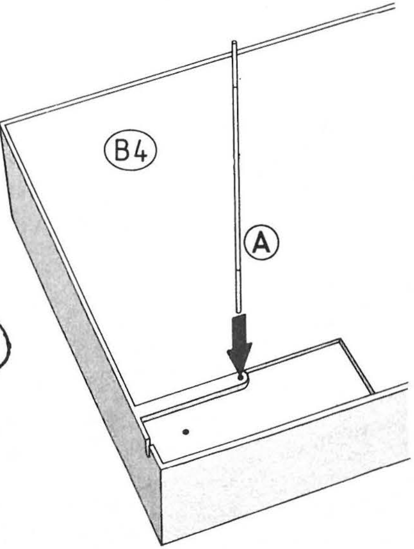
The electronic X 3000 kit contains little packets full of short and long pieces of wire; we will now bend these as shown in the accompanying diagrams. Begin with the longer pieces of wire.

In order that the connectors look good, that is, are not crooked, you will have to push the insulation along the wires. If the insulation is missing from one or both ends then you must make sure that the bare wires are the same length. If they are different lengths then the insulation can be removed appropriately (Fig. B3).



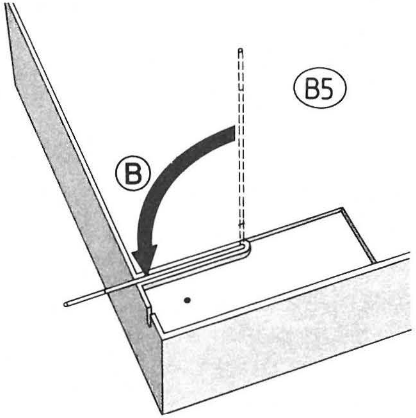
B3

(A) Next insert the end of the wire into the little hole in the rib above the KOSMOS label (Fig. B4).



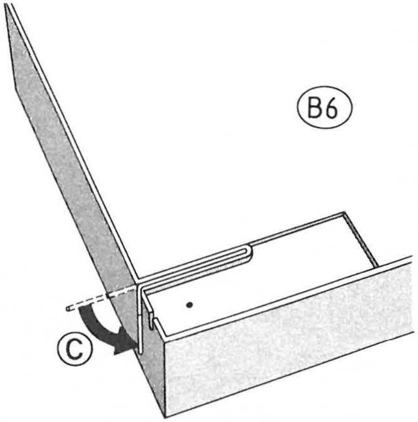
B4

(B) Now bend the wire in a right angle towards the edge of the board, as shown in Fig. B5.



B5

(C) In the next stage we complete the bending of the wire (Fig. B6).



B6

My tip:
Do everything in the order given!
1.
2.
3.
4.

(D) Now remove the little pieces of insulation from either end of the wire, which now looks like that in Fig. B7. It has a **span** of exactly 30 mm and will be called the **long wire connector** in the research circuits.

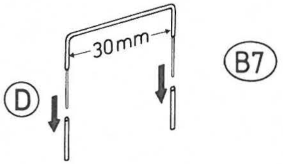
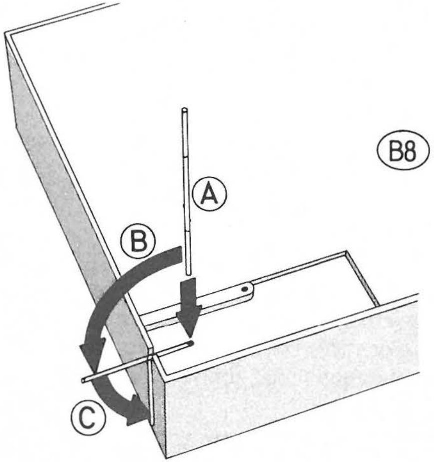
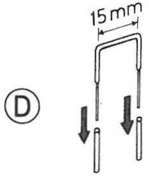


Figure B8 shows how the short pieces of wire are bent. To do this insert the short piece of wire into the little hole below the rib. Then repeat stages A to D in the same order. These connectors have a span of 15 mm and are referred to as the **short wire connectors**. The wire connectors are now ready and all you need to do is to connect the 9V battery and then you can construct your first research circuit.



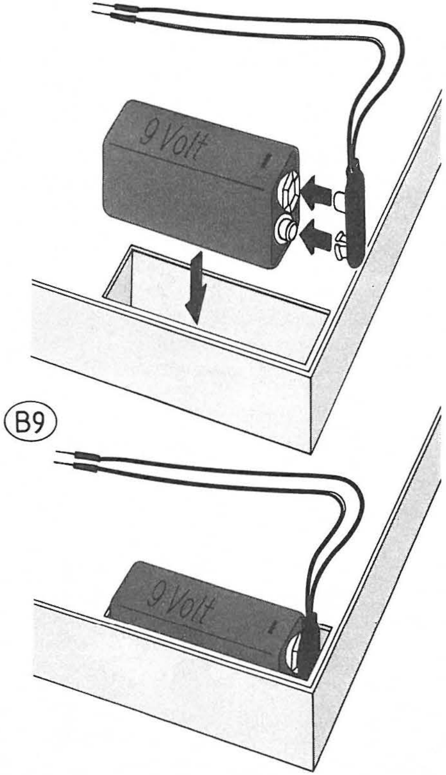


Beware!

The bare ends of the battery leads must not come into contact (short circuit).

Connection of the 9V battery

The type 6 F 22 9V battery is attached to the battery clip as shown in Fig. B9 and then inserted in the battery compartment at the edge of the plug board. You should use the battery clip with little round plugs; the battery clip with cable eyes is intended for mounting in the console housing. The red lead is positive, the black lead is negative.



1. Straight into electronics...

that is where this book of experiments is going to lead us in the shortest and most interesting way. We do not want any boring accounts to hold us up, no we will start experimenting right away. The very first few experiments will show you that interesting circuits can be built up from the simplest of components. Your practical experience and theoretical knowledge will grow with each experiment so that you will feel at home with electronics by the time you have completed the series of experiments that are described here.
Some of the electronic components are sensitive and they take it amiss if they are not handled correctly. The following components must never simply be connected to the power supply (battery or power supply) (Fig. 1):

the transistors
the germanium and silicon diodes
the amplifier module
the phototransistor
the infrared diode
the light-emitting diode (LED)

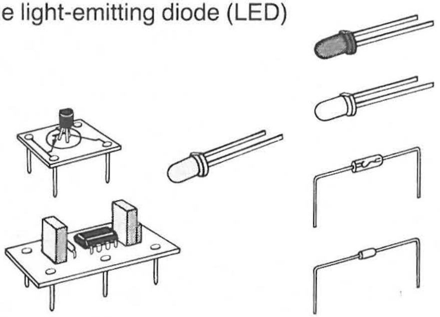


Fig. 1 Components that must not be connected to the battery alone.

This warning applies particularly to the light-emitting diode (Fig. 2) which is often mistaken for a light bulb by beginners.

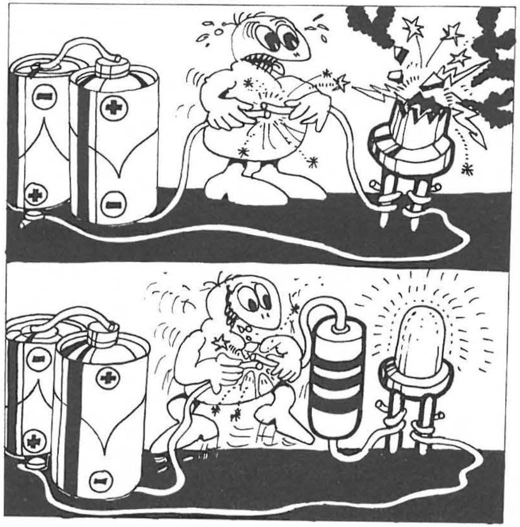


Fig. 2 Never operate light-emitting diodes without a protective resistor!

1.1 Six components are enough for an electronic warning blinker with integrated circuit

The following components are required (Fig. 3):
amplifier module
insulating board (see insert)
light-emitting diode
capacitor 100 microfarad (100 μF)
resistor 15 kilo ohm (color code: brown-green-orange)
resistor 100 kilo ohm (colour code: brown-black-yellow)
resistor 470 ohm (color code: yellow-violet-brown)
short and long wire connectors
Insert the components as in Fig. 4.

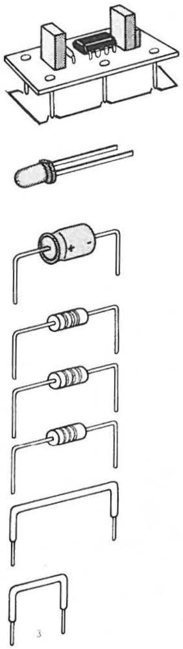


Fig. 3 Components required for the warning blinker

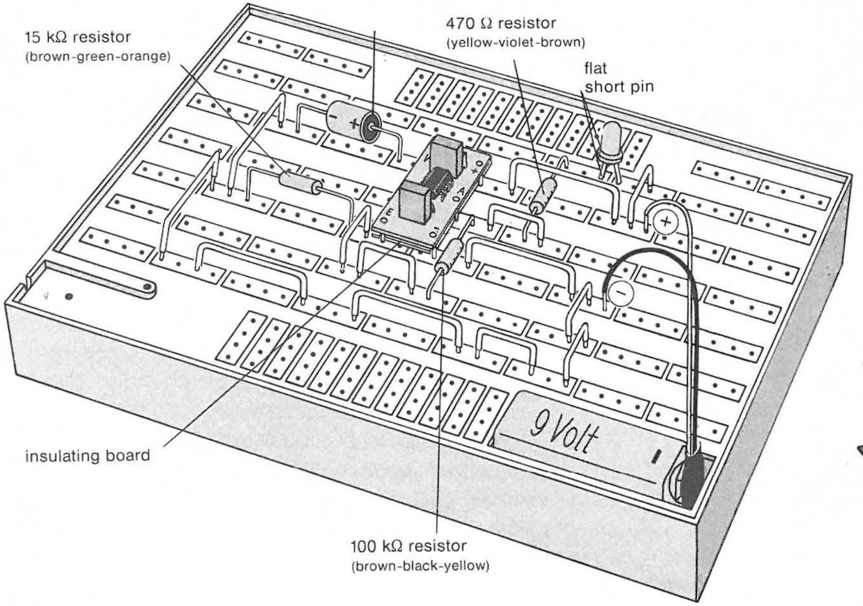
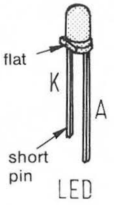

15 kΩ resistor
(brown-green-orange)
470 Ω resistor
(yellow-violet-brown)
flat
short pin
9 Volt
insulating board
100 kΩ resistor
(brown-black-yellow)

Fig. 4 Construction of circuit 5


flat
K
A
short
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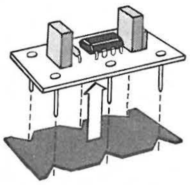
LED


insulating board
underneath

Even though your warning blinker is only made up of half a dozen components it is a masterpiece of technology. The light-emitting diode winks on and off uninterruptedly; it would blink for hours, days, weeks or months without human interference and without the mechanical movement of a single contact.

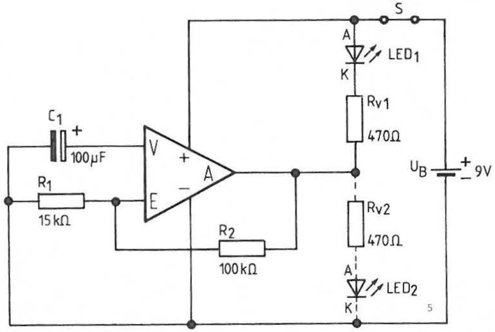
Your light-emitting diode will blink about twice a second, that means it would switch on and off about 172,800 times per day. If you were to attempt this with a normal light switch then – if we assume a working life of 1 million switchings – this would not last even for one week. The amplifier module is the heart of the warning blinker. An explanation will be given later of why we use an amplifier in a blinker circuit and how the whole thing works.

Here we can only reveal that the actual amplifier is the little black box on top of the module. Inside it does not contain individual components soldered into a circuit, it is rather an integrated circuit (= IC) where the components – 17 transistors, 6 resistors and 4 diodes – are combined on a tiny semi-conductor chip only a few square millimeters in area by means of a highly complicated process.

1.2 The circuit diagram – building instructions in a telegraphic style

The experiment book always contains two different diagrams of each circuit; these are the representational diagram and the circuit diagram. The representational diagram is intended to make it easier for you to construct the circuit and shows how the parts are arranged on the plug board and where the leads should be inserted.

The circuit diagram, on the other hand, shows, in a simplified manner, how the components are connected together and does not take any account of how they are arranged in space. Its purpose is to make it easier to explain the function of the circuit. Circuit diagrams are sometimes known in the literature as current flow diagrams.


S
A
LED1
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Rv1
470Ω
C1
+
100µF
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A
−
E
R1
15kΩ
R2
100kΩ
UB
+
9V
Rv2
470Ω
A
LED2
K
5

Fig. 5 Warning blinker

Figure 5 is the circuit diagram of your electronically controlled blinker. For simplicity's sake the amplifier module is represented merely as a triangle, even though the chip also contains some capacitors and a resistor, which are necessary for the operation of the module as an amplifier unit. However, since an amplifier is always symbolized as a triangle in electronics, we will do the same too.

1.3 Ground without floor

Electronics specialists are always referring to "ground" or "earth". These words stem from the days of grandfather's "steam radio". These sets always had a solid, heavy metal chassis which was connected to one of the pins of the power supply. The same principle is used nowadays in automobiles. A look under the hood will reveal to you that a thick cable leads from one of the terminals of the battery to the engine block. This is a substitute for the "ground" (Fig. 6)!
Grandfather's radio has disappeared, but the term ground remains in electronics. What is meant by it?
The answer is simple. The electronics specialist decides to which pole of a battery he is going to refer all the voltage levels in his circuit; in principle it does not matter which pole it is, but it has become customary in electronic circuits to refer to the negative pole as ground and to measure all voltages with respect to the negative pole (that is with respect to ground). So remember! Negative is ground.

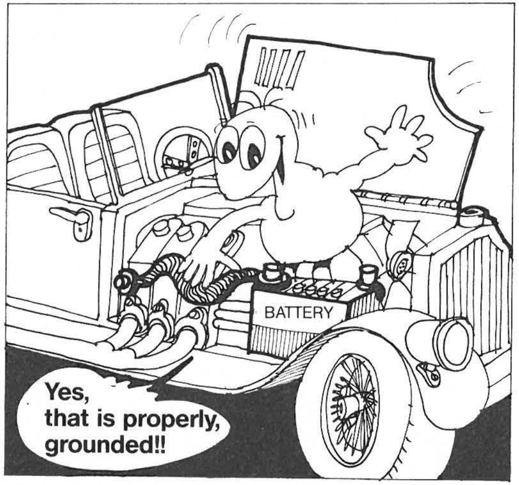
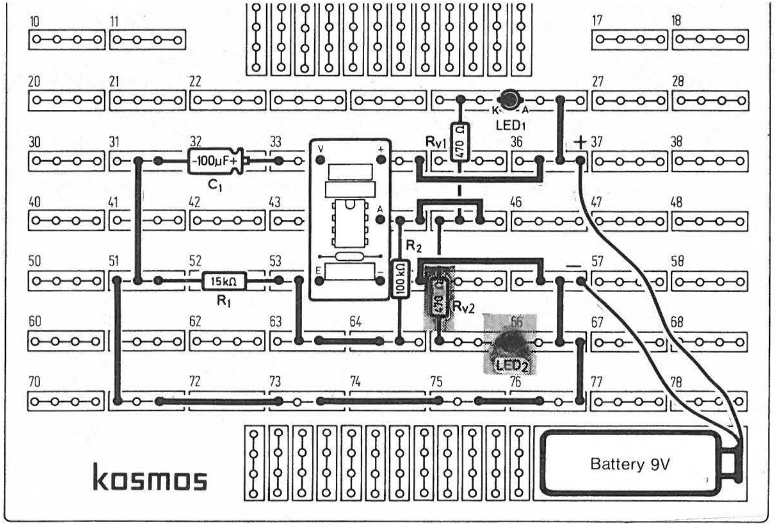

BATTERY
Yes, that is properly, grounded!!

Fig. 6 You can see what is meant by ground in an automobile.

1.4. Making two from one; alternating blinker

You can see a second light-emitting diode drawn in grey in Fig. 7 (the broken line in circuit 5) with its preresistor (470 ohm), color code: yellow-violet-brown. When these two components are added to the circuit the simple blinker becomes an alternating blinker; one LED goes out when the other lights up.
Leave the alternating blinker set up for other experiments; now you are going to set up the console housing.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-100µF+
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470 Ω
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+ 37
38
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43
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47
48
R2
50
51
52
15kΩ
R1
53
100 kΩ
470 Ω
Rv2
– 57
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LED2
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kosmos
Battery 9V

Fig. 7 Double warning blinker

2. Mounting the console housing

Now you are going to assemble the console housing and equip it with loudspeaker, battery and potentiometers. Set out the following components ready:

The switch console,
the loudspeaker,
the decorative cover,
potentiometer strip P1,
potentiometer strip P2,
the battery clip with lead connections,
the large adjusting knob,
the small adjusting knob,
the connecting rod
and the small screws.

In addition you need a screwdriver, a kitchen cloth and a little household detergent.

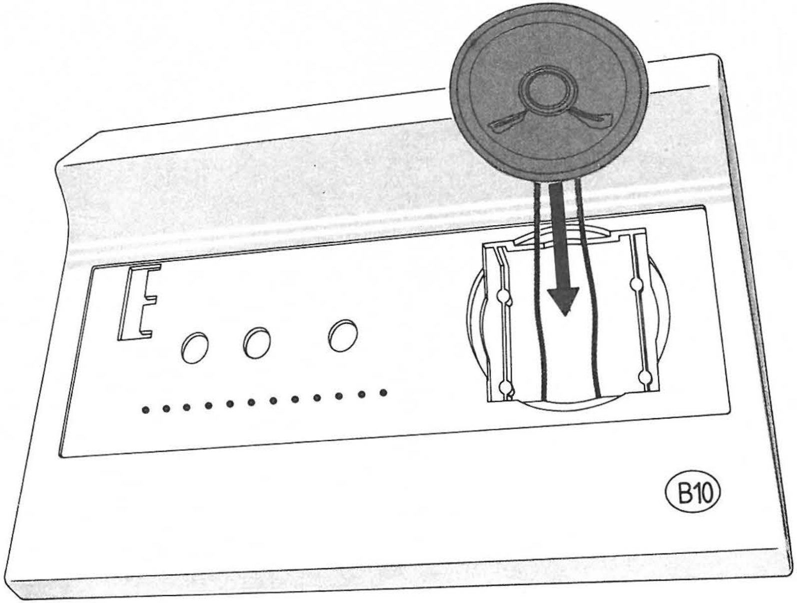
First wash the top of the switch console with the household detergent and water. This is necessary to make sure that the adhesive backing of the decorative cover attaches satisfactorily later. There could be traces of grease and parting agent left on the console housing from when it was injection molded.

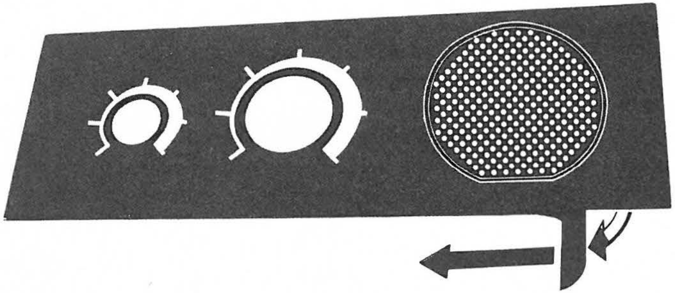
Important! Rinse the detergent off again thoroughly with plenty of water and then wipe completely dry.

You can now begin to mount the loudspeaker. Figure B10 shows how the loudspeaker is inserted into the console housing from the top. The two connecting leads are led out downwards to the front of the console.

Now take the decorative cover and detach it from its backing paper. If you carefully bend a corner of the decorative cover in both directions you will be able to get a hold on the backing paper and it will come away easily (Fig. B11).

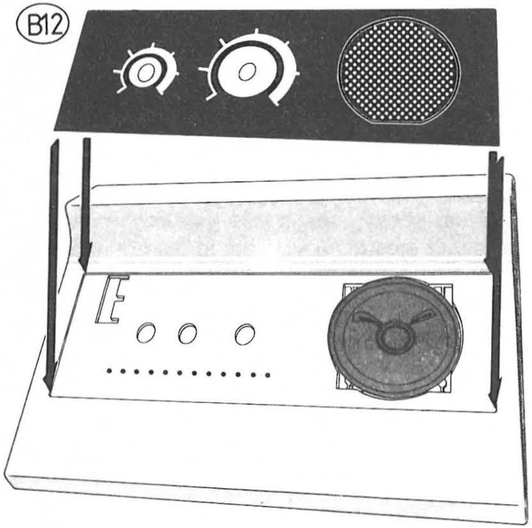
Important! Do not touch the sticky side with your fingers.





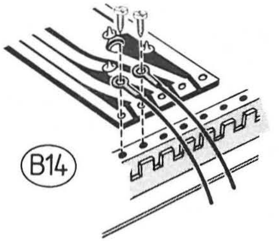
Now carefully lay the decorative cover in position on the console housing and press it down (Fig. B12).

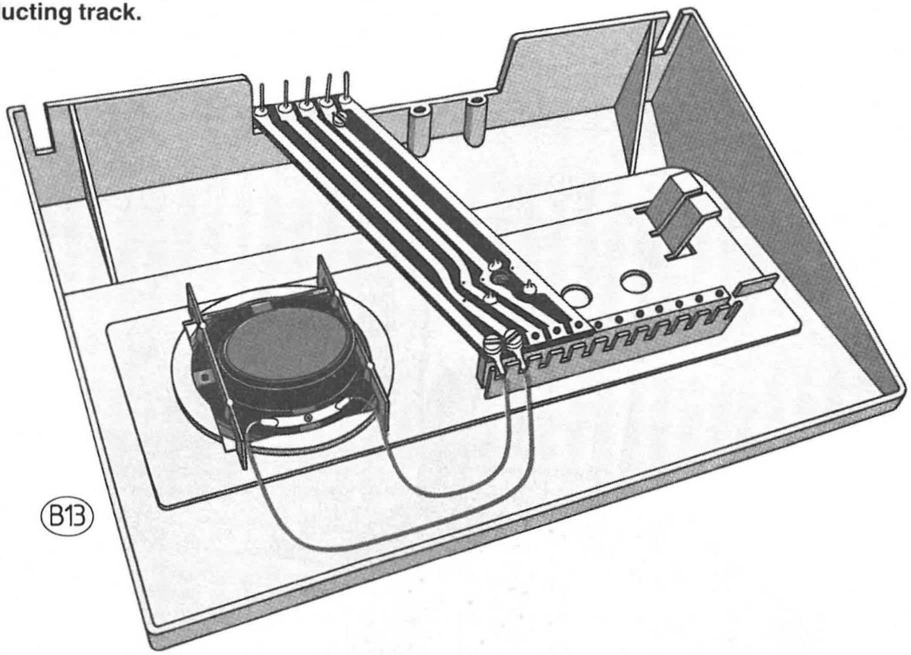
Important! Only press the decorative cover down at the edges of the loudspeaker, otherwise the cover could stick to the speaker membrane.


B12

Now turn the console housing over and insert potentiometer strip P1 so that the conductor track and the five pins are upwards (see Fig. B13). The strip P1 is mounted to the left-hand side of the switching console (next to the loudspeaker). The potentiometer strip is fixed on one side by two screws, the two loops of the loudspeaker leads are clamped immediately under the heads of these screws. Figures B13 and B14 show where the screws have to be inserted. First start all the screws in their holes and then tighten them up one after the other.

Important! Attach the two leads to the outer left-hand side of the conducting tracks and make sure that the loops are in contact with the conducting track.


B14

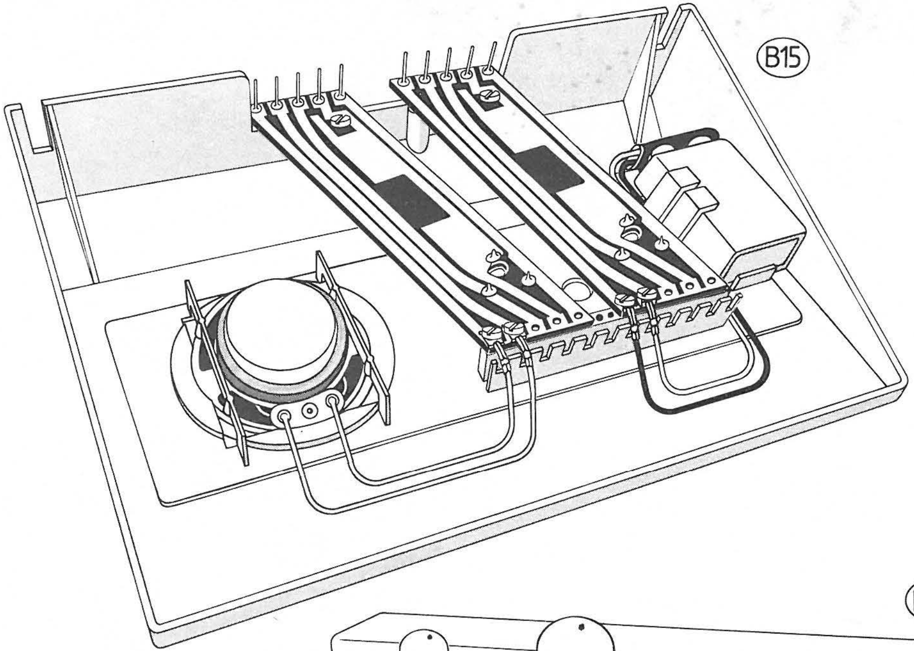

B13

Next insert potentiometer strip P2, Fig. 15 shows that this strip is mounted on the right-hand side of the console. Attach the loops of the battery clips to the two left-hand conductor tracks. **Attach the black (−) lead to the left outer conductor track, the red lead (+) is attached to the next conductor track to this.**

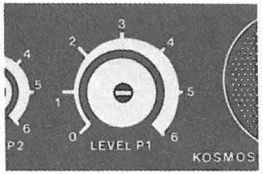
Important! These two connections should on no account be made incorrectly otherwise the circuits will not function and components could even be damaged.

Each potentiometer strip is also fastened down by another screw at the edge of the console; fasten these now.
Attach the 9 volt battery to its clip and insert it in the holder provided (see Fig. B15).
You can now attach the adjustment knobs; to do this turn the control console over. The potentiometer sockets and the knob connections do not fit each other in every position. So turn the potentionmeter contact clips with a small screwdriver until they are positioned as illustrated in Fig. B16 (view of the decorative cover at P1).
Then attach the two adjusting knobs from above, as shown in Fig. B17. Make sure in each case that the marker is pointing at number 3 on the scale. You should also push upwards from below so that the potentiometer strips are not damaged when the knobs are inserted.

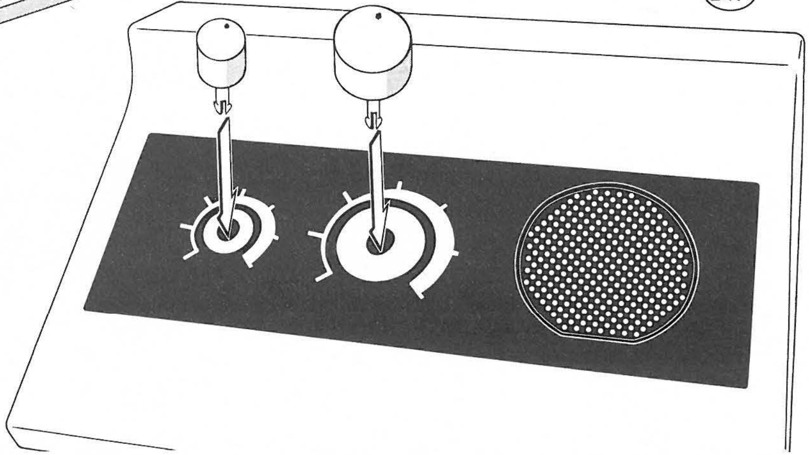
B15



B16

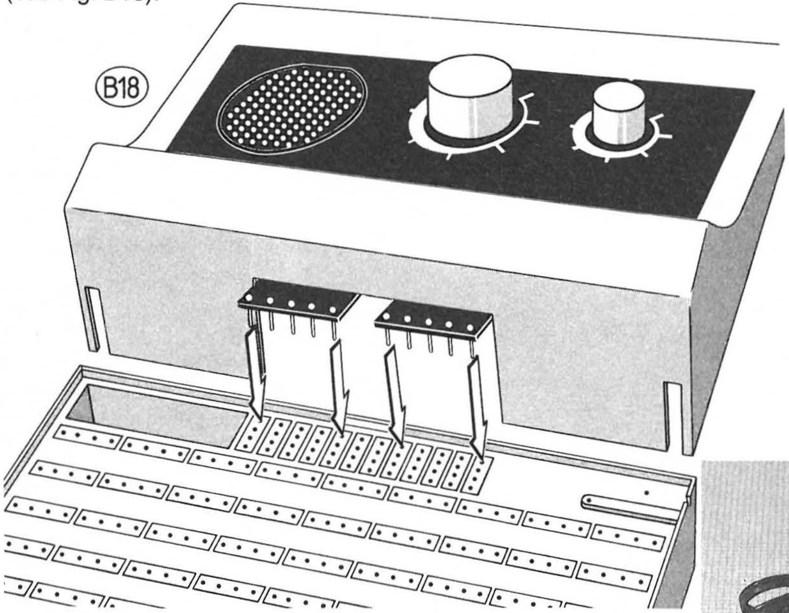


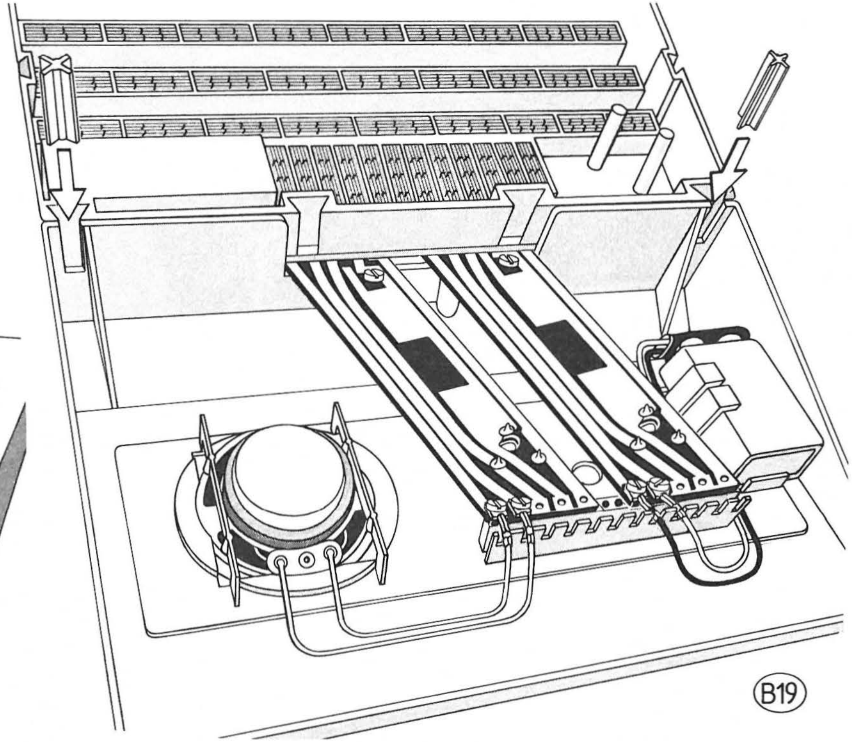
B17



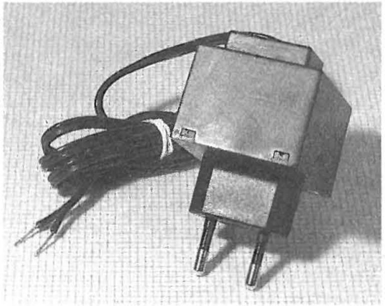
Mounting the switch console on the plug board

Now plug the completed switch console onto the plug board that is completely equipped with sockets. The plug board should have the KOSMOS label towards the console.
Lower the switch console onto the plug board from above, making sure that the ten contact pins are inserted into the appropriate contact clips (see Fig. B18).





Important! The KOSMOS power supply can also be connected instead of the batteries; in this case it is essential that the batteries be detached first.



The switch console/plug board unit can now be carefully turned over and a connecting strip inserted in each of the outer grooves from below (see Fig. B19). The mounting work is now complete.

3. Blinking, clicking, testing

3.1 A blink-click circuit

If the light-emitting diode LED 1 and its protecting resistor are removed and the loudspeaker is connected in series with a capacitor then the alternating blinker will become an optical *and* acoustic signal; it is necessary in addition to connect the battery housed in the switch console to the circuit by means of two wire connectors. Figure 9 shows the construction and the circuit diagram is illustrated in Fig. 8.

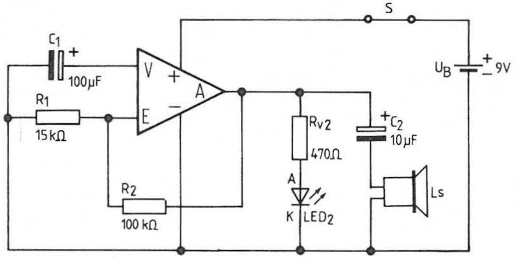

C1
+
100µF
R1
15kΩ
V
+
A
E
−
S
U_B
+
9V
Rv2
470Ω
+C2
10µF
A
K
LED2
Ls
R2
100 kΩ

Fig. 8 The blink-click circuit

Each time the light-emitting diode LED 2 goes out there will be a clicking noise. Musicians could use such a circuit as a metronome (i.e. a time keeper) and later you will see that is possible to adjust the "ticking rate" continuously – from blues to rock'n roll.
Incidentally: The **wire connector S** between plug 62 and the plug at the positive output of the console housing can be used as an **on-off switch.** Just pull out the connector when you want to switch off.

3.2 The amplifier creates a sound

It is now possible to make a further test of the versatility of your first experimental circuit. Take out the 100 μF capacitor and replace it with a 100 nF capacitor (this capacitor is sometimes also labelled 0.1 μF or even just 0.1).
A shrill alarm signal will sound immediately. This circuit will do good service in various alarm systems. It is known as a tone generator.

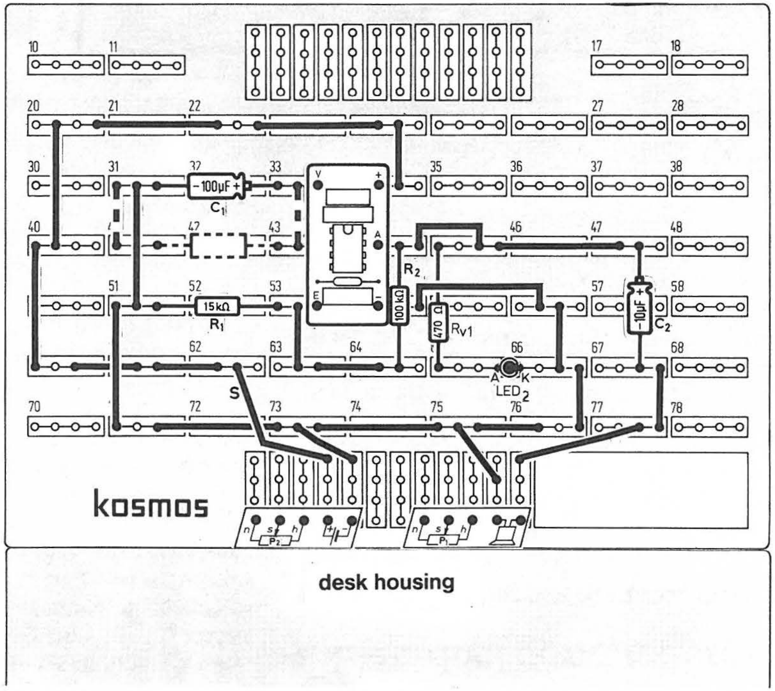

10
11
17
18
20
21
22
27
28
30
31
32
33
35
36
37
38
−100µF+
C1
V
+
A
E
40
42
43
46
47
48
R2
51
52
53
15kΩ
R1
100 kΩ
470 Ω
Rv1
57
58
10µF
C2
62
63
64
66
67
68
A
K
LED2
S
70
72
73
74
75
76
77
78
kosmos
P2
P1
desk housing

Fig. 9 Construction of circuit 8

It is naturally possible to alter the pitch of the sound. If a further 100 nF capacitor (it can also be labelled with 0.1 µ) is added – broken line in Fig. 9 – then the sound becomes significantly lower.

3.3 Making conduction audible: a conduction tester

A conduction tester will be a very great help to you in your experiments concerning the nature of an electric current. With it you will be able to check whether or not an object is conducting or nonconducting.

The tone generator is somewhat rebuilt for this purpose (construction diagram Fig. 11, circuit diagram Fig. 10). Remove the wire connector between plug 22 and plug 24 and the LED with its protective resistor and insert a long connector into plug 22 and another into plug 24. These wires are employed as "measurement probes". You can test their functioning now; hold the bare ends of the wire in contact with each other, a sound will be produced immediately.

Leave the conduction tester assembled, we will now do another small but instructive experiment.

4. Electrical conduction

4.1 To conduct or not to conduct, that is the question

You cannot see electric current, but you can make its effects visible with, for example, indicators. You did this in the warning blinker in the first experiment with the LED.

Set up a measuring circuit according to Figs. 12 and 13 on the second board, for use in further experiments. In order to provide the current remove the battery from the holder in the switch console, remove the battery clip and attach the second clip (included in the kit).

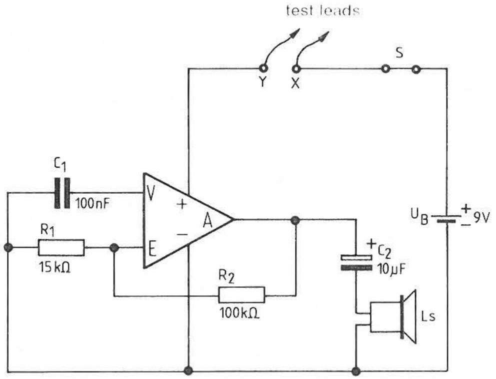

test leads
S
Y
X
C1
100nF
R1
15kΩ
V
E
A
+
−
R2
100kΩ
+C2
10µF
UB
+9V
Ls

Fig. 10 Conduction tester

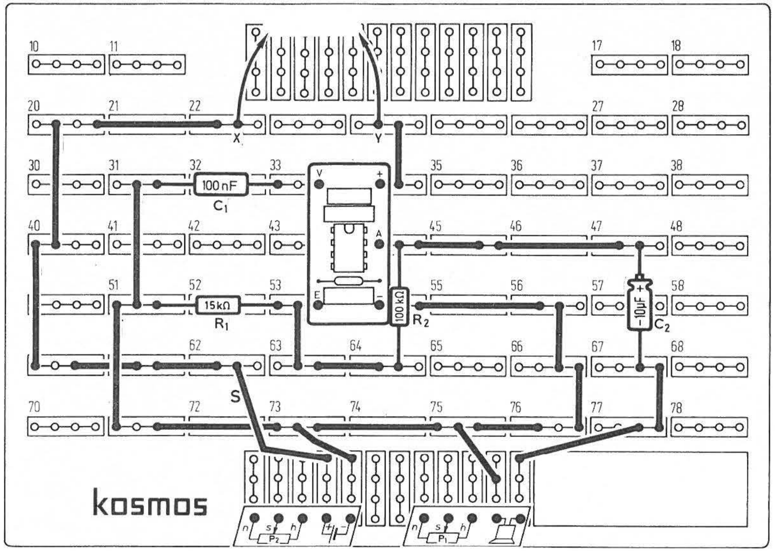

10
11
17
18
20
21
22
27
28
X
Y
30
31
32
33
35
36
37
38
100 nF
C1
V
+
40
41
42
43
A
45
46
47
48
51
52
53
E
55
56
57
58
15 kΩ
R1
100 kΩ
R2
10µF
C2
62
63
64
65
66
67
68
S
70
72
73
74
75
76
77
78
kosmos
P2
P1

Fig. 11 Construction of circuit 10

It could not be simpler. The whole circuit consists of the LED and its series resistor *Rx*. The x means that resistors of various values are to be tried out. Insert them in the order:

470 ohm (yellow-violet-brown)
1 k ohm (brown-black-red)
1.5 k ohm (brown-green-red)
3.3 k ohm (orange-orange-red)
5.6 k ohm (green-blue-red)
10 k ohm (brown-black-orange)
15 k ohm (brown-green-orange)
33 k ohm (orange-orange-orange)

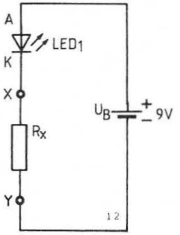

A
LED1
K
X
Rx
UB
+
9V
Y
12

Fig. 12 Simple circuit

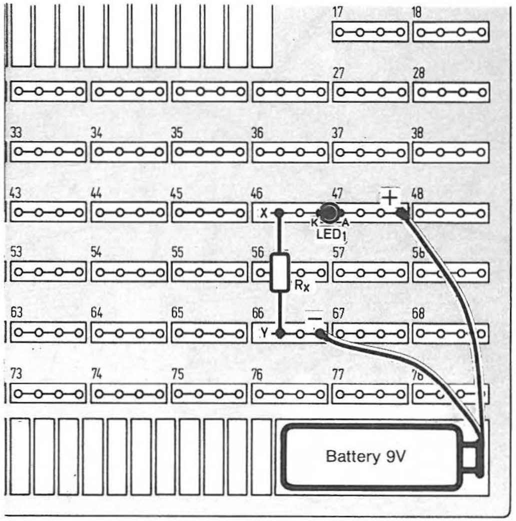
You will find that a higher current evidently flows through the lowest (470 ohm) resistor (the LED is bright), on the other hand, only a small current flows through the largest (33 k ohm) resistor (the LED only glows).

So the amount of current flowing in the circuit can be adjusted by changing the resistance. The 33 k ohm resistor is evidently a poorer conductor than the 470 ohm resistor.

If you take *Rx* away completely and do not substitute it with anything, there is nothing connecting x and y but air and, of course, the plastic of the plug board. Plastic and air are extraordinarily bad conductors; they are known as nonconductors or insulators.

Figure 14 shows some examples of how you can use your conduction tester (according to Fig. 11)

Fig. 13 Construction of circuit 12


17
18
27
28
33
34
35
36
37
38
43
44
45
46
47
48
X
K
A
LED1
+
53
54
55
56
57
58
Rx
63
64
65
66
67
68
Y
−
73
74
75
76
77
78
Battery 9V

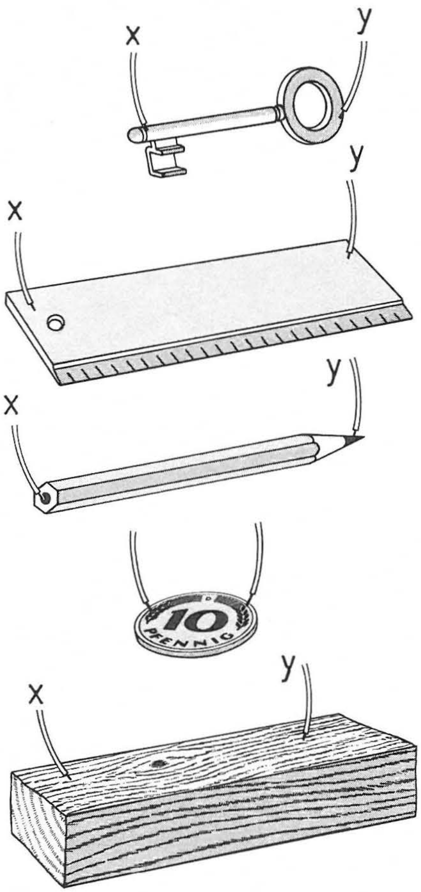

x
y
x
y
x
y
10
PFENNIG
x
y

Fig. 14 Testing various objects for their conductivity

to find out what things conduct and what things do not. (Do not forget to replace the battery!)
If the wires are touched on a key, for example, the conduction tester produces a tone. The key is metal, it conducts. You can test everything you can get your hands on. Objects with a resistance of less than about 2 k ohm will yield a tweet with the conduction tester. The human body also conducts electricity, but considerably less well than does a metallic object. Your nervous system cannot detect currents that are as weak as the ones you are using in this experiment. They are completely safe. For instance, if – while the speaker is sounding – you touch the bare ends of the 100 k ohm resistor *R2* of the conduction tester with moistened thumb and forefinger, then the tone of the speaker will fall as a sign that an extraordinarily small but detectable current is flowing through your body.

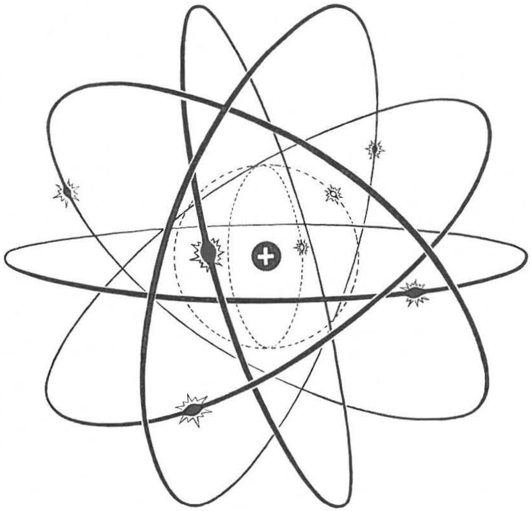


Fig. 15 Bohr-Rutherford atomic model of a nitrogen atom. The outer shell contains five electrons.

4.2 Particles of the indivisible

Atomos, the indivisible, is what the Ancient Greek philosophers called the smallest particles of matter. The name has been retained, but our conception of the smallest units of matter has changed completely. We know nowadays that atoms are also made up of particles; they consist of nuclei made up of positively charged protons and neutral neutrons, which are surrounded by a mantle made up of negatively charged electrons. The electrons orbit the nucleus at an extremely high velocity at various set distances. In accordance with these various distances we can imagine the mantle of electrons as if it were a series of shells one inside the other, rather like the skins of an onion (Fig. 15).
We have only considered one atom until now. What happens when there are many atoms together, as for example in a piece of copper wire? If you imagine the atoms as being tiny little spheres, the copper wire is made up of closely packed spheres. However, these are not just arranged higgledy-piggledy next to each other but rather in a particular spatial pattern; this is known as the **crystal lattice** (Fig. 16).
In such an arrangement the outer shells of the atoms overlap so that the electrons in these outer shells no longer belong to one particular atom but are electrons which are shared with the neighboring atoms.
In metals these electrons in the outer shells are so mobile that they can travel from atom to atom and migrate through the metal lattice. If these electrons migrate in a particular direction then an electrical current flows.

Thus a substance can only conduct if mobile electrons are present in it. But even amongst the metals, all of which contain mobile electrons, there are differences in the conductivity. This is because of differences in the structures of the atomic lattice.

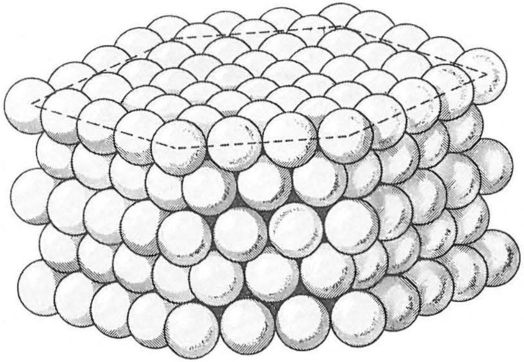


Fig. 16 Hexagonal crystal lattice. For reasons of clarity the overlaps of the outer spheres are not shown.

The electrons are subjected to frictional resistance during their migration through the atomic lattice. The amount of friction that occurs varies from metal to metal. The more resistance there is the lower the conductivity. Thus the two quantities bear an inversely proportional relationship to each other, or mathematically:

$$\text{conductivity} = \frac{1}{\text{resistance}} \tag{F1}$$

The conductivity is measured in Siemens, abbreviated to S and the resistance in ohms, abbreviated to Ω GV (Omega).

5. Electrical potential

5.1 The force that moves electrons

We have discovered that the migration of electrons in one direction constitutes a flow of electrical current. It is now high time to pose the question as to what it is that causes the electrons to migrate in a particular direction.

The answer is not very difficult: No object is set in motion without the action of a force. The force that displaces electrons is known as the electrical potential and is represented by the symbol U, its magnitude is measured in volts (abbreviated to V) (in honor of the Italian physicist Count Alessandro Volta, 1745-1825). You will recognize the term electrical potential (or voltage) from batteries and electric sockets.

What electrical potential is will be clear to you from Figs. 17 and 18. A water circuit is fitted with a pump that produces a pressure (Fig. 17). As long as the slide closes the tube the water cannot move in the tube but simply pushes against the slide. The right-hand diagram shows the same situation in an electrical circuit; the battery provides an electrical potential, but a current cannot flow, because there is a piece of plastic (an insulator) between the two conducting contact springs.

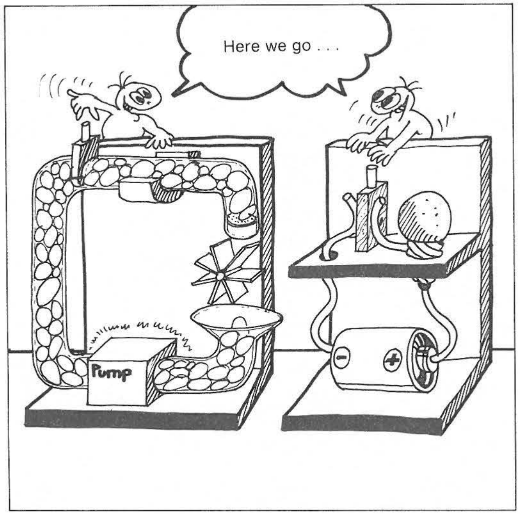


Fig. 17 Interrupted circuit

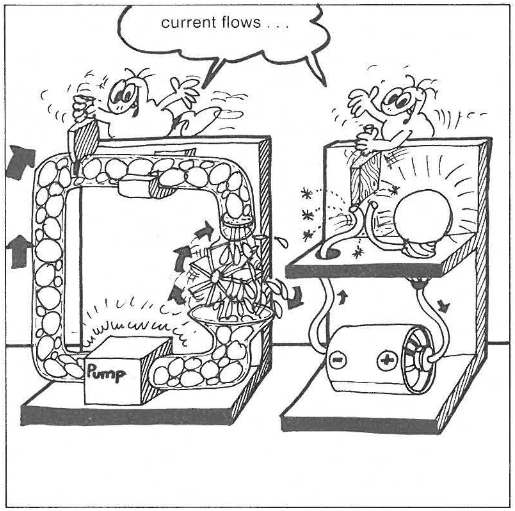


Fig. 18 Current flows; just as the copper wire itself has a slight resistance, so the pebbles act to impede the water flow.

Figure 18 shows what happens when the slide and the insulator are removed.

The water flows through the pipe and drives the turbine. The current flows through the electrical circuit and lights the lamp. Just as the copper wire has a very small but measurable resistance, the water pipe also has a resistance caused by the pebbles.

This experiment, which you are carrying out in your head, can be extended by additionally packing the water pipe with sand and equipping the electrical circuit with the device you already know as a resistor (Fig. 19).

The water or the current now flows more slowly in both systems, the turbine does not rotate as

rapidly and the lamp glows less brightly. What do we need to do to increase the pressure in the water pipe and the electrical potential in the circuit?
We must obtain a second pump for the water circuit or increase the voltage in the electrical circuit by inserting a second (or several more) batteries in the circuit "in series" with the first as it is termed.

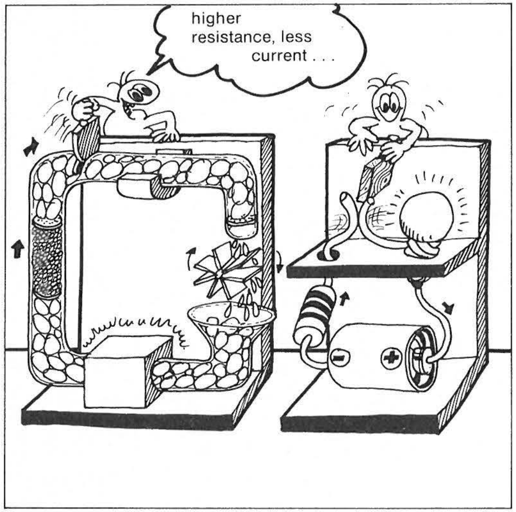


Fig. 19 Packing with sand brings a greater resistance into the water circuit.

5.2 More volts by series connection

Figure 20 shows the "insides" of one of the 9V battery packs you use. You will see to your amazement that it contains 6 small 1 x cell batteries, each of which produces 1.5V. All these 1.5V batteries are connected in series so that the total voltage produced is the sum of the individual potentials:

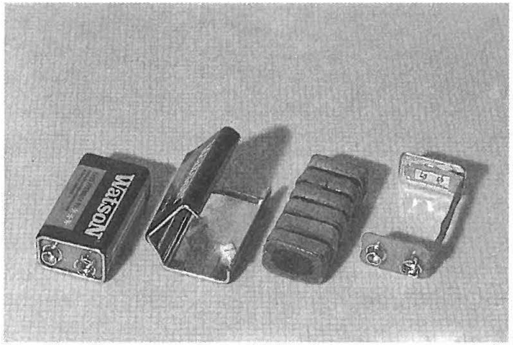
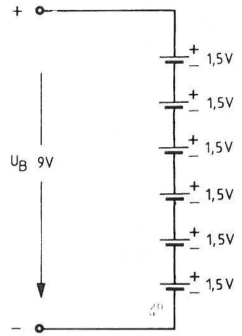


Fig. 20 The inside of our 9V power pack

$$U_{tot} = U1 + U2 + U3 + \ldots + \ldots$$

(F2) $$U_{tot} = U1 + U2 + U3 + \ldots$$

or expressed in numbers:
9V = 1.5V + 1.5V + 1.5V + 1.5V + 1.5V + 1.5V.



5.3 Plus is too few and minus is a great deal

You now know that electrical current is the result of the migration of electrons, the negatively charged particles of matter. There is an excess of electrons at the negative terminal of the battery. The electrons migrate from the negative pole to the positive pole.
Nevertheless, many textbooks say that electricity flows from positive to negative, which would certainly agree with the idea that positive = a lot and negative = a little.
How did this error come about?
The apparent contradiction has a historical basis. Electricity was already being investigated at a time when almost nothing was known about the structure of matter.
We can follow the lines of thought of the pioneers

of electricity (the American Benjamin Franklin and the German Georg Christoph Lichtenberg) by means of a very simple experiment with frictional electricity.

On a day when the air is dry take a plastic ruler (polystyrene) and rub it with a dry cotton handkerchief (Fig. 21) This will cause the ruler to acquire a negative charge, i.e. its surface "scratches" electrons out of the cotton handkerchief and these now sit, thickly packed, on its surface and await an opportunity to jump off. If you bring the charged ruler slowly towards your nose, it will feel as if you are pushing your nose into a spider's web. What you can feel are the electrons jumping from the ruler, which you have thus made personal contact with.

These were assumed to be positive carriers of electricity. The fact that these charged carriers, the electrons, were later assigned a negative charge, causes people concerned with electronics problems even today. In electrical technology the conventional current direction from positive to negative is utilized even today, even though it is known perfectly well that the charged carriers, the negative electrons, travel from the negative to the positive pole.

5.4 Exorcising ghosts electronically

A great many people with a tendency to believe in the occult become the victims of fraud and some have their pockets lightened on being swindled by scientific charlatans, who cash in with plausible tricks.

We are going to carry out a spiritualistic seance electronically and to do this you should construct the circuit in Fig. 23. Push a 15 cm long piece of wire like a rod aerial into contact clip 43 and lay it more or less vertical (circuit diagram 23). The experiment, for which you should wear shoes with leather or rubber soles, is carried out in a carpeted room; place the apparatus on a table and form an "O" with your thumb and forefinger; sur-

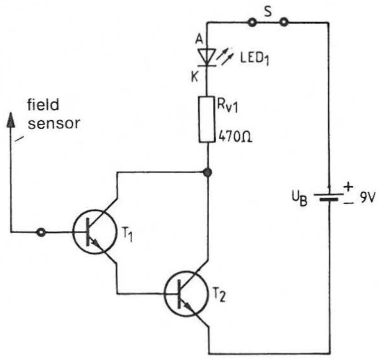
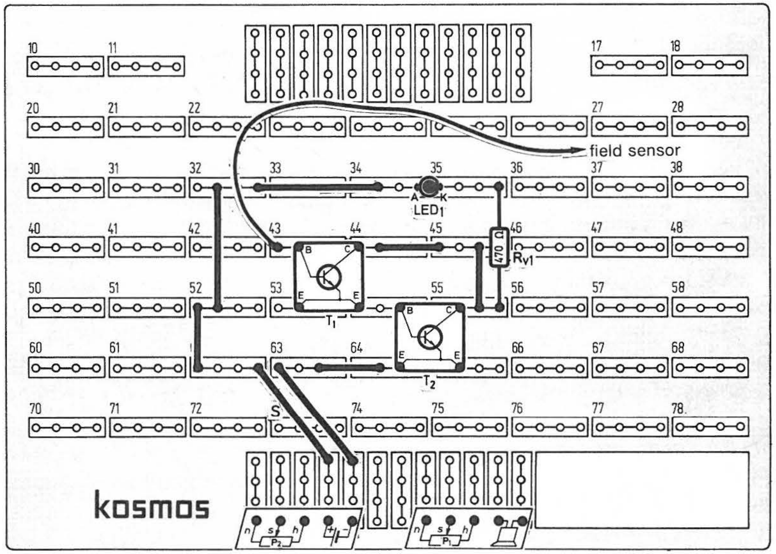


Fig. 23 Electronic ghost exorcism

Fig. 22 The construction of circuit 23



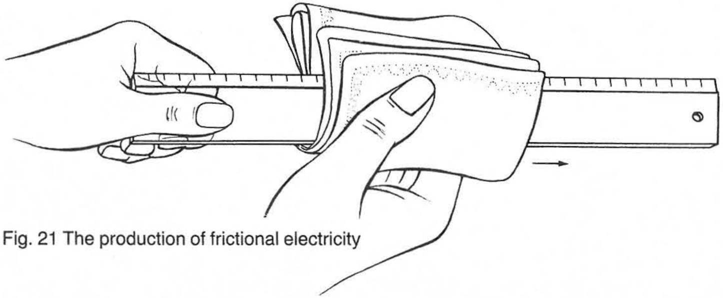


Fig. 21 The production of frictional electricity

round the horizontal wire with this O, naturally without touching any portion of the circuit. Now wipe your feet hard a couple of times. The ghost exorcism works; the LED will begin to flicker in a mysterious way. If you do not have a carpet then you can perform the following experiment. Rub a plastic ruler with a dry cotton handkerchief and then wave it rapidly over the horizontal wire as if you were using a bow on a violin string. The LED will flicker mysteriously once again! Is this a case of magic?

The electrons that have sprung across onto your "field detector" exert a repulsive effect on the electrons already in the copper wire and displace them a little. If you regard such forces as hocus-pocus (technically they are known as field forces) then you can answer yes if you like. Educated contempories will accept the fact that an electronic displacing force exists, quite soberly, as a law of nature and recognize that the displacement of electrons is nothing more than an electric current (that we have amplified tremendously in our experiment by means of two transistors).

5.5 Electronic polar expedition

It is not always terribly easy to find out which is the positive and which is the negative pole of a current source, like for instance a normal flashlight battery. For this reason you will now construct a universal polarity tester on the second plug board which you have available.

The construction of such a polarity tester is shown in Fig. 24. The polarity tester consists of the two LEDs and a 470 ohm protective resistor. A battery (up to 12 volts!) can be connected either way round at points A and E. If LED 1 illuminates then A is attached to the negative pole, if LED 2 illuminates then the negative pole is at E.

The detectors of the polarity tester are the light-emitting diodes. They light up when a current flows through them. Their secret is that, in contrast to a filament lamp, they only allow the current to flow in one direction. In your circuit the two LEDs are mounted in opposite directions (anti-parallel). This means that current can always flow through one of them. Naturally it is possible to check the polarity of a battery you need for an experiment. Figure 25 shows the necessary connections and Fig. 26 the necessary circuit diagram. LEDs are semiconductor components. They are significantly more robust than normal light bulbs and have a very long life. The choice of the correct materials allows the production of red, yellow, green, orange and, more recently, blue light.

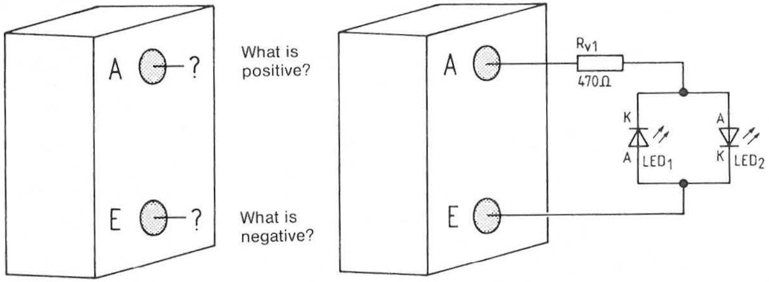


Fig. 24 Diagram of a polarity tester

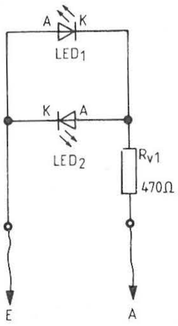
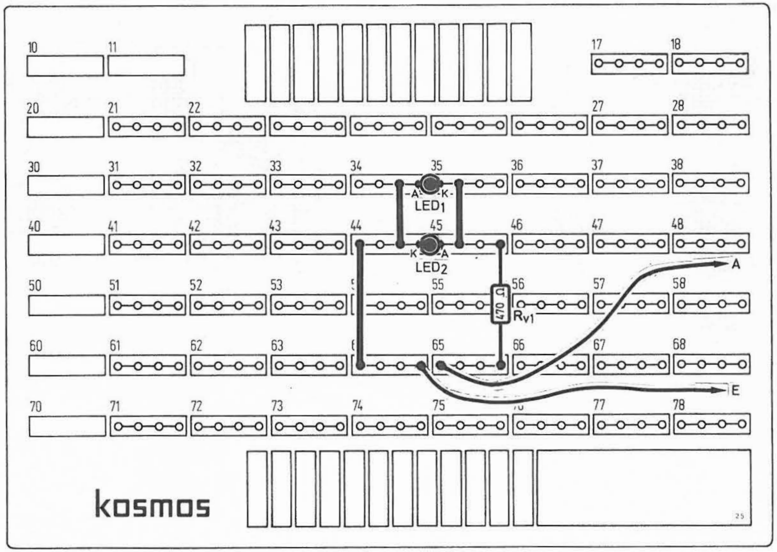


Fig. 26 Circuit of the polarity tester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K
LED$_1$
40
41
42
43
44
45
46
47
48
K
A
LED$_2$
A
50
51
52
53
55
56
57
58
470 Ω
R_{V1}
60
61
62
63
65
66
67
68
E
70
71
72
73
74
75
77
78
kosmos
25

Fig. 25 Construction of circuit 26

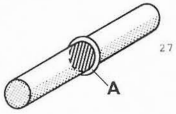


Fig. 27 The current strength tells us how many electrons are passing through a cross section in unit time.

6. Electric current

6.1 How many electrons flow

The current strength *I* tells us how many electrons flow in a particular time past a particular point in the circuit.
Figure 27 will help you to understand this more precisely. It shows a piece of wire which is marked on the outside by a ring at A. It encloses the cross section shown hatched at this point.

A current of one ampere (1A) is flowing when 6.25 trillion, that is 6 250 000 000 000 000 000 or 6.25 x 10^{18} electrons migrate through the cross section per second. The unit ampere (A) is named after the French physicist Andre Marie Ampere (1775-1836).
So as far as the strength of the current is concerned it does not matter how rapidly the electrons migrate (the technical term is drift) but rather how many pass in a particular time.
Let us compare the electrons with hikers who are walking leisurely along a path four abreast (Fig. 28).
They then come to a bridge that is so narrow that there is only room for one person at a time. The walkers then have to go in single file and pass over the bridge at a run if they all want to do it in the same time. The "current strength" is the

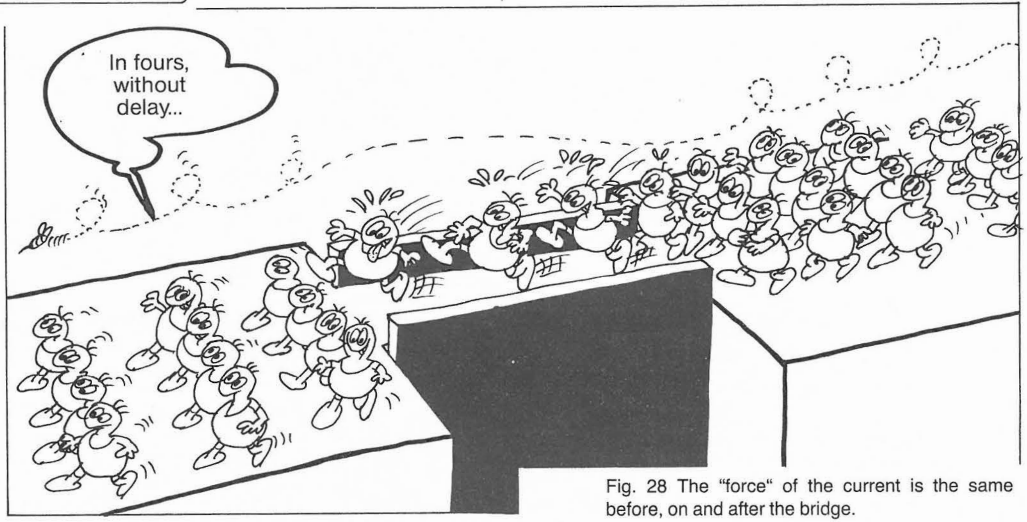

In fours, without delay...

Fig. 28 The "force" of the current is the same before, on and after the bridge.

same, before, on and after the bridge, the "drift velocity" on the narrow bridge is four times as high. The various widths of path represent the various cross sections of wires of various thicknesses. The drift velocity of the electrons depends on the numbers of electrons that can flow through the cross section of the conductor alongside each other. When the cross section is halved then only half the number can flow alongside each other and the drift velocity must be doubled in order to maintain the same current. This naturally requires a higher "pressure" (potential). A conductor with a smaller cross section offers the current a higher resistance than does a thicker wire. Longer wires have a higher resistance than shorter wires of the same diameter. The material a conductor is constructed of also plays a role in determining its resistance, alongside its length and cross section. For instance silver conducts better than copper, copper better than aluminum. This property of the substance is known as its specific resistance.

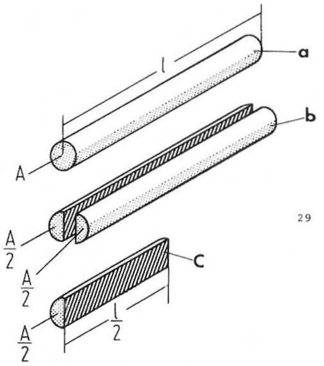


Fig. 29 The arrangement of equal resistance

An example of the relationship between conductor cross section, conductor length and resistance is illustrated in Fig. 29. The wire a has the same resistance as two wires set in parallel b, each having half the cross section. Wire c also has the same resistance even though it has only half the cross section of wire a, since it is also only half as long. The specific resistances of materials normally employed are listed in Table 1.

Table 1 Specific resistances

Material	ρ_{20}
Silver	0.0163
Copper	0.0175
Aluminum	0.0294
Zinc	0.0625
Iron ca.	0.13
CuNi 44	0.49

The symbol for the specific resistance is the Greek letter rho (ρ). Since the specific resistance is temperature-dependent a suffix is included stating the temperature at which it is measured. The values in the table were all obtained at 20 degrees Celsius.

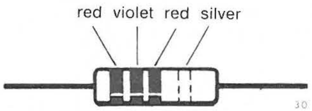
The relationship between specific resistance, conductor length and conductor cross section can be expressed in a formula:

$$\text{(F3)} \quad \text{Resistance of a wire} = \frac{\text{Spec. resistance } (\Omega\,\text{mm}^2/\text{m}) \cdot \text{length}}{\text{sectional area } (\text{mm}^2)}$$

6.2 Pop art on resistors

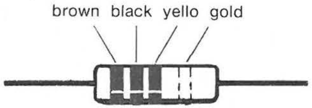
It will be clear to you from the last section that "resistance" is a property of matter and not an electronic component. It is a certain sloppiness of speech on the part of the practitioners of electronics that causes them sometimes to refer to the components themselves as "resistances", the more precise physicist calls them resistors or, even today, uses the more exact term "rheostat". Today's industrially produced resistors are little sausages with colorful bands on them to reveal their ohmic values. The principle of the markings is very simple: Each color corresponds to a particular number. Black = 0, brown = 1, red = 2, orange = 3, yellow = 4, green = 5, blue = 6, violet = 7, gray = 8 and white = 9. The colors are read off from left to right, whereby right is the end with a silver or gold ring (or sometimes a red ring somewhat separated from the rest). The two left-hand rings correspond to the digits and the third to the number of zeros to be added to them.

Fig. 30 Example of the color coding of a resistor of 2.7 kilo-ohm and 10% tolerance


red
violet
red
silver
30

From left to right
red = 2
violet = 7
red = 2 zeros
silver = 10% tolerance
2,700 Ω
or
2.7kΩ

Fig. 31 Example of the color coding of a resistor of 100 kilo-ohm and 5% tolerance


brown
black
yello
gold

From left to right
brown = 1
black = 0
yellow = 4 zeros
gold = 5% tolerance
100,000 Ω
or
100kΩ

6.3 It depends on the sum

What would happen in the case of our water model in Section 5.1 if we were to add a second sand packing in the pipeline?
The resistance of the pipeline would increase and the water flow would therefore decrease.

You can test this by building a simple circuit according to Fig. 32 (circuit diagram 33). The LED will glow brightly. Now remove wire connector x and replace it by a second 470 ohm resistor; you will observe a decrease in the brightness. The two separate resistors of 470 ohm each here make up a total resistance of

$$R_{tot} = 470\ \text{Ohm} + 470\ \text{Ohm} = 940\ \text{Ohm}.$$

This can be expressed as the formula:

(F4) $$R_{tot} = R1 + R2 + R3 + \ldots + \ldots$$

The next experiment tells you whether the resistors need to be in a fixed order. To do this swap the positions of the LED and the resistor. You will not be able to detect any difference in the brightness of the LED. The current intensity is evidently independent of the order of the components in

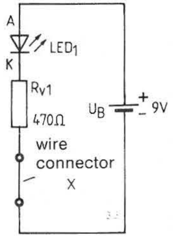
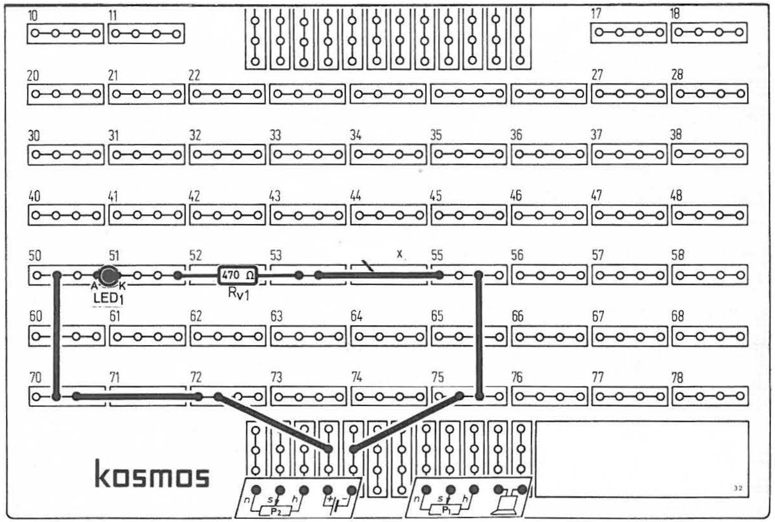

A
LED1
K
Rv1
470Ω
UB
+
-
9V
wire connector
X
33

Fig. 33 A second resistor is fitted in place of the wire connector.

Fig. 32 Construction of circuit 33


10
11
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41
42
43
44
45
46
47
48
50
51
52
53
x
55
56
57
58
470 Ω
A
K
LED1
Rv1
60
61
62
63
64
65
66
67
68
70
71
72
73
74
75
76
77
78
kosmos
P2
P1
32

the circuit. If you remove the two 470-Ω-resistors and replace them by a 1-kΩ-resistor and a wire connector, then the brightness will also remain the same, since twice 470Ω gives a resistance of 940Ω which is not significantly different from the 1000Ω value of the 1-kΩ-resistor.

6.4 100 meters sprint – not for electrons!

How rapidly do electrons actually travel? Let us say we have put a conductor under a particular potential that causes a current of 10 electrons per second. If the conductor contains a large number of mobile electrons to carry the current, e.g. 10000, then the individual electrons only require a very small velocity for 10 electrons per second to pass. If, on the other hand, there are fewer mobile electrons (i.e. the resistance is higher), then the individual electrons have to put on a bit of spurt in order to achieve the required current flow. The physicists have developed a formula to describe the relationship.

(F5)

Electron velocity equals:

$$\frac{\text{current strength} \cdot \text{length of conductor}}{\text{number of mobile electrons in the concuctor}}$$

Example: If we use this formula for a current of 1 ampere (1A) = 6.25×10^{18} electrons per second. A copper wire 60.4 mm long and 0.5 mm in diameter contains 10^{21} free electrons (the values are rounded off to get a simple number of electrons). Then it can be calculated that:

$$\text{velocity} = \frac{(6.25 \cdot 10^{18}) \cdot 60.4}{10^{21}} = 0.378 \text{ m/s}$$

The low velocity at which the electrons in the conductor travel is amazing!

6.5 Drift velocity and running time

If you switch on an electric light in the stairway, all the lights go on simultaneously. Does that not seem extraordinary in view of the low drift rate of the electrons discussed in the last example? However two different phenomena have to be considered here and you must not confuse them on any account. One is the drift rate of the electrons and the other is the propagation time of the switching impulse.

It is rather like a railroad: A train enters a terminal station and all the passengers climb out. The locomotive is at the buffer stop, the last car is way out along the track. The locomotive engineer waits until all the passengers have climbed out, before he reverses the train from the station to the sidings.

When the train slowly starts to roll backwards, the locomotive and all the cars start at virtually the same time (Fig. 34). The short time required for the buffers between the cars to be compressed and the last car way out on the track to start is the propagation time of the starting impulse. The whole train is now in motion (current flows) but it takes a long time before the locomotive reaches the spot way out on the track where the last car originally stood. The fact that all the lights on the stairway to go on at once does not mean that those electrons that were at the switch at the time

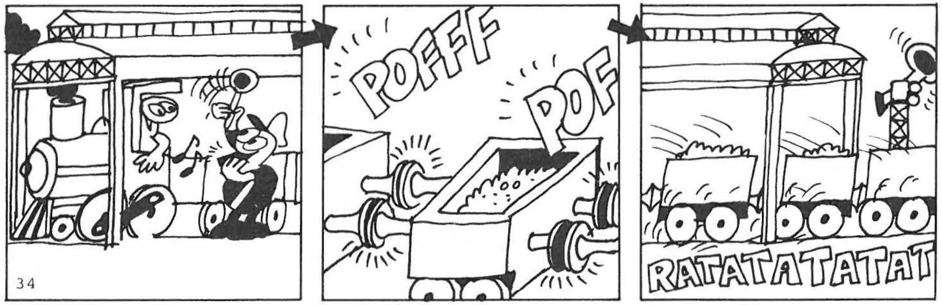


Fig. 34 (from left to right) The current is switched on; the impulse is propagated rapidly; the current is now flowing; the electron from the switch has now reached the lamp (see text).

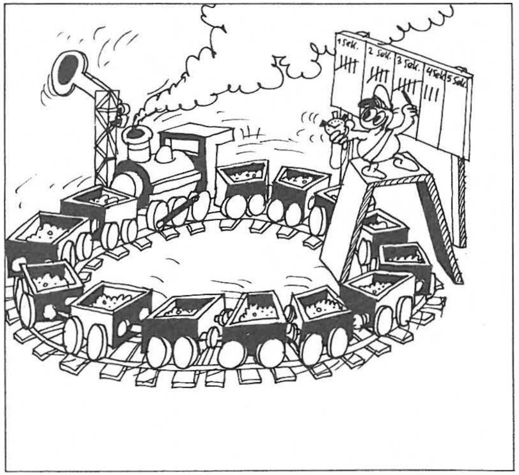

1 Sek.
2 Sek.
3 Sek.
4 Sek.
5 Sek.

Fig. 35 The same number of railroad cars passes every part of the track per unit time.

of switching on have travelled all the way to the topmost lamp.

The current is the same everywhere in a closed circuit. The same number of electrons per second pass every portion of the circuit. If you compare a circuit with a circle of track with a railroad train that is so long that the locomotive is pushing the last car in front of it, then it is quite clear that the same number of cars per second passes every point in the circuit (Fig. 35). The current remains the same at every point even when the circuit is made up of differing resistances. The drift velocity, on the other hand, can be different in different parts of the circuit; it depends on the cross section and the available free electrons.

7. Ohm's law

During his lifetime the German physicist Georg Simon Ohm (1789-1854) was well-known for his dislike of inaccuracy. In spite of this it has been his lot that his date of birth is often wrongly quoted, because of the ease with which the number 9, as it was written by the clerk on his birth certificate, can be confused with the modern way of writing 7; this even led to his 150th birthday being celebrated 2 years too soon. This error is still perpetuated in several reference books.

Ohm was the first to recognize the dependence between potential, resistance and current in a circuit and he published his findings in the form of a law in 1827 – what we now know as Ohm's law.

7.1 How high is the current strength?

Set up the circuit illustrated in Fig. 36 and turn the adjustment knob of potentiometer P1 back and forth (circuit diagram 37). You will see that the brightness of the LED varies significantly with the setting of the potentiometer. As you adjust the potentiometer you introduce more or less of its carbon track into the circuit, thus changing its total resistance.

The fact that changing the resistance also changes the current intensity constitutes one of the three statements of Ohm's law:- At constant

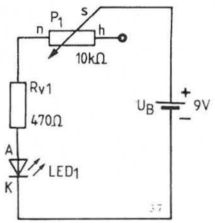
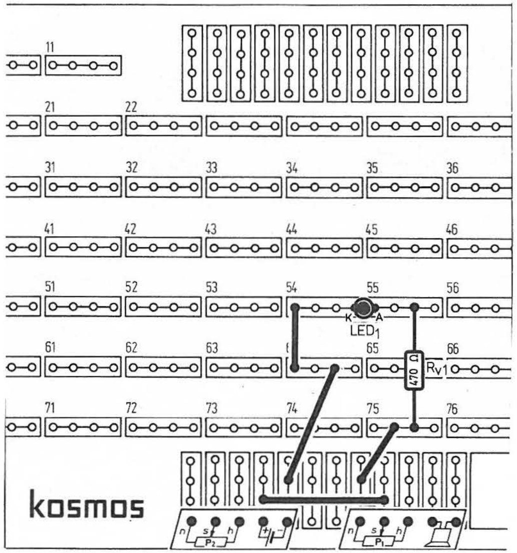


Fig. 37 Potentiometer in circuit

Fig. 36 Construction of circuit 37



potential the strength of the current flowing is dependent on the resistance.

It is possible to express this relationship in a formula, which can be employed to calculate the current strength, if the potential and the resistance are known:

current = potential/resistance.

The specialist does not write this formula in words, he uses letter symbols which are internationally recognized. The resistance is represented by the letter *R*, the current flowing by *I* and the potential by *U*.

The question arises here as to why the letter Ω is not employed for the resistance, A for the current and V for the potential.

The answer is simple; we need to distinguish between the underlying fundamental physical quantities and the units they are expressed in. Thus, for example, time is a physical quantity represented by the letter *t*. This can be measured in various units such as the second s, the hour h, the minute min and the day d.

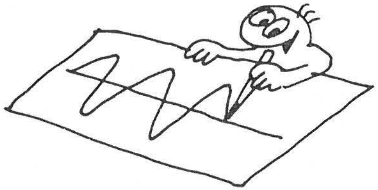
According to convention the abbreviations for physical quantities are written in italics and the abbreviations for units of measurement in normal script. This makes it possible to recognize at a glance the meaning of an abbreviation in a calculation. Table 2 provides a list of the letter symbols that you have already met and will be using later.

Table 2 The units employed for physical quantities

Physical quantitiy	Symbol	Unit	Symbol
time	*t*	second	s
frequency	*f*	Hertz	Hz
potential	*U*	volt	V
current	*I*	ampere	A
resistance	*R*	ohm	Ω

We can now write the relationship described by Ohm's law in terms of the formula:

$$I=\frac{U}{R} \tag{F6}$$



Example: Set $U = 9\mathrm{V}$ and $R = 100000\Omega$ ($100\mathrm{k}\Omega$), then:

$I = 9\mathrm{V}/100000\Omega \quad = 0.00009\mathrm{A}$

or

$I = 0.09\mathrm{mA}$ or $90\mu\mathrm{A}$

The prefixes "milli" (m) and "micro" (μ) allow the numbers to be represented in an intelligible manner. Table 3 lists the internationally accepted prefixes that we will employ.

Table 3 Designation of powers of ten

Factor	Power of ten	Prefix	Abbreviation
x 1000000 (million)	10^{6}	mega	M
x 1000 (thousand)	10^{3}	kilo	k
x 0.001 (thousandth)	10^{-3}	milli	m
x 0.000001 (millionth)	10^{-6}	micro	μ
x 0.000000001 (thousand millionth)	10^{-9}	nano	n
x 0.000000000001 (million millionth)	10^{-12}	pico	p

7.2 Resistances can also be calculated

When the current and the battery potential in a circuit are known then it is possible to calculate the total resistance of the circuit. To do this it is necessary to rewrite formula F6 as follows:

$$R=\frac{U}{I} \tag{F7}$$

This is the second statement of Ohm's law.

Example: A circuit with unknown resistance *Rx* and a LED are under a potential of 9V from a battery. The current in the circuit is measured as

15.7mA (with the meter from KOSMOS electronic X 4000 for example). If the 1.6V drop which always occurs at a LED is subtracted from the 9V then the unknown resistance is overcome with a voltage drop of 7.4V. This means that the resistance can be calculated:

$$R_x = 7.4\text{V}/15.7\text{mA} = 471\Omega$$

Evidently this is the 470-Ω-resistor you are familiar with, whose actual ohm value is slightly different from its nominal value (tolerance).

7.3 All good things come in threes

The two formulae F6 and F7 show that the current does notjust depend on the resistance of the circuit but also on the potential of the battery.
If you wish to calculate the potential that is necessary to drive a certain current through a fixed resistance, then you must use formula F8, which is obtained by rewriting one of the two previous formulae. This is the third statement of Ohm's law.

(F8) $U = I \cdot R$

Formula F8 is also suitable for the calculation of the "potential drop", i.e. the potential difference between the connections of a resistor.
Example: A current of 5mA flows through a 1-kΩ-resistor. Therefore there is a potential of across its connections.

$$U = 1\text{k}\Omega \cdot 5\text{ mA} = 5\text{V}$$

It will lead to a significant improvement in your understanding of electrical processes if you accustom yourself to mentally translating the word "potential" into "potential drop" or "potential difference" and, at the same time, consider between which two points this potential difference occurs. Just as you can give a walker in the mountains the height he has to climb from the valley to a mountain hut, so in electronics you can quote a potential difference between any two points.

7.4 Divided potential

Think back to the experiment in Fig. 36. When you turned the adjustment knob you were able to change the brightness of the LED continually but – perhaps you did not notice – it was not possible to extinguish the LED completely. Look at circuit diagram 37 again and you will immediately see why. When the complete carbon track of the potentiometer is included in the circuit, that is when the full 10Ω of the potentiometer is expressed, then according to formula F4 the total resistance is:

10kΩ + 470Ω = 10.47kΩ.

With this resistance the current through the LED is sufficient to cause it to glow slightly. Things are arranged differently in Fig. 39; this time the potentiometer is arranged as a "potential divider" (construction diagram 38).

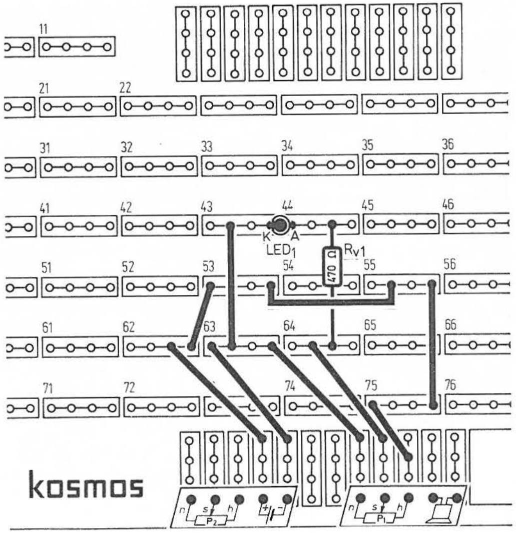


Fig. 38 Construction of circuit 39

Fig. 39 Potentiometer as voltage divider

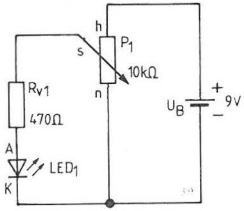


Figure 40 indicates what a potential divider does. The busy man with the crank can adjust in steps to various potentials between 0V and +9V (0V is the starting point, ground, that is the negative ter-

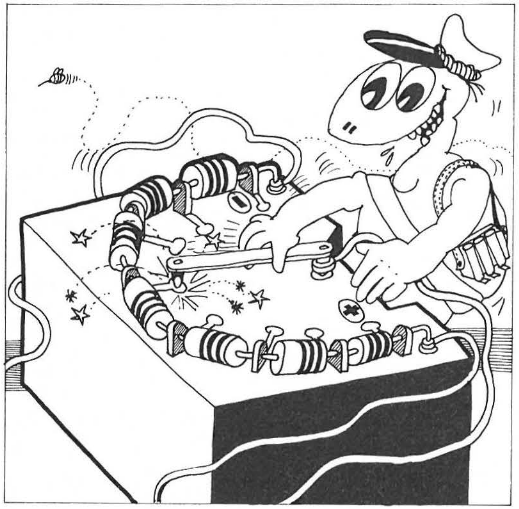


Fig. 40 The voltage divider

minal of the battery). The "divided" potential is available at the connection to the crank. Unfortunately the number of different potentials available is limited by the number of resistors connected in series. The man would have to mount an infinite number of resistors in order to be able to obtain any desired potential between 0V and +9V. Life would be much easier for him if he could use a potentiometer like that pictured in Fig. 42. The slide can be used to select any desired potential between 0V and +9V by moving along the carbon track.

A chain of resistors with two or more links as in Fig. 41 or a potentiometer like Fig. 42 is known as a **potential divider**.

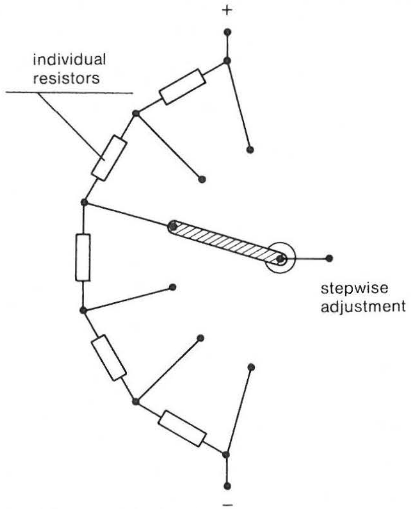


Fig. 41 Voltage divider from fixed resistors

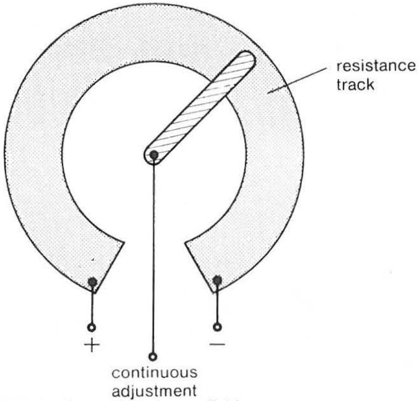


Fig. 42 Potentiometer-voltage divider

It is now clear that the LED in circuit 39 will go out completely, when the contact of the potentiometer is moved in the direction of the negative pole of the battery. The potential that is taken will become ever smaller, it will eventually be reduced to a value so small that there is not enough power to drive sufficient electrons through the diode.

Note: we have always labelled the three connections of the potentiometer n, s, and h; "n" has been used to label the "low" potential side (you can easily remember this if you think of the "nether" regions); this means that when it is **turned to the left** the slide "s" moves towards this connection. Similarly "h" stands for high; that is the connection towards which the slide moves when the knob is **turned to the right**.

8. The capacitor: an electron accumulator

The blinking light circuit at the beginning contained a capacitor as well as the components you recognize.

How is it constructed, how does it function?

The simplest capacitor consists of two metal plates with "nothing" between them. The quotation marks are there because by "nothing" is meant a vacuum, that is a space containing no air (Fig. 43). A vacuum is an ideal insulator!

The capacitors in your experimental equipment do not have a vacuum between their plates, but an insulating material, e.g. plastic film. The insulating material between the plates of a capacitor is known as a **dielectric** pronounced di-electric (Fig. 44).

You can demonstrate the rather puzzling properties of a capacitor in the following experiment (Fig. 45):

The 100-μF-capacitor is in a circuit with the battery and the loudspeaker (circuit diagram 46).

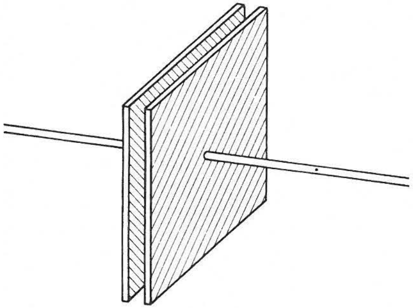
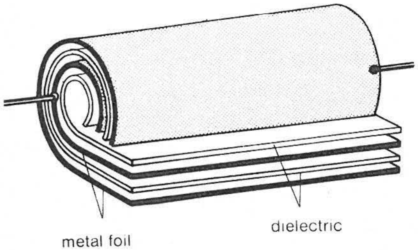


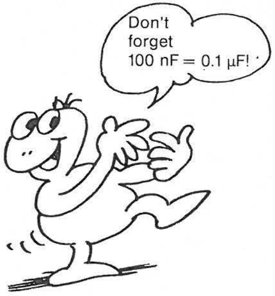
Fig. 43 There is "nothing" (vacuum) between the plates of an ideal capacitor.

Fig. 44 Diagram of a wound capacitor



When the wire connector X is inserted at the end you will hear a slight but distinct click from the loudspeaker. A current has obviously flowed for a short period!

Ignore for the moment the wire connector represented by a broken line. Remove the wire connector and insert it in accordance with the broken line; the loudspeaker is now directly connected to the capacitor. You will again distinctly hear a slight click.


Don't forget 100 nF = 0.1 µF!

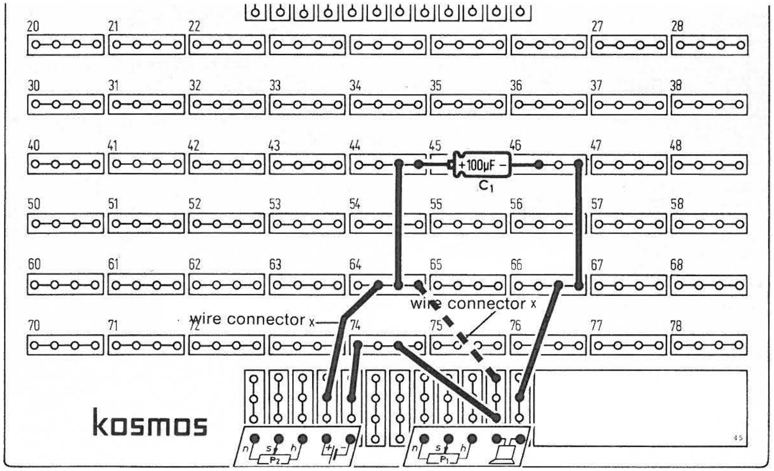


Fig. 45 Construction of circuit 46

Experiment suggestion:- You can try out the other capacitors in the kit in place of the 100μF-one.

The fact that a current flowed for a short time in spite of the insulating material between the plates of the capacitor seems to go against everything you have learnt up till now, for an insulator (or a vacuum) is supposed to stop the flow of current. The secret of a capacitor lies in the action of electrical charges at a distance; let us look more closely at this "action at a distance".

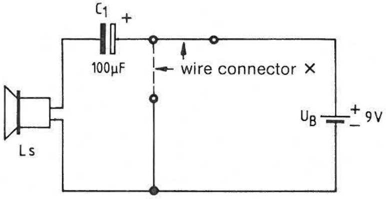


Fig. 46 Current flows through the capacitor for a short time.

8.1 Action at a distance

What do two electrons do if we imagine them to be hanging in a vacuum at the ends of two threads?

They exert a force on each other and since they possess the same (negative) charge, they repel each other. Two opposite charges, on the other hand, would attract each other.

Forces of this nature, they are known as electric

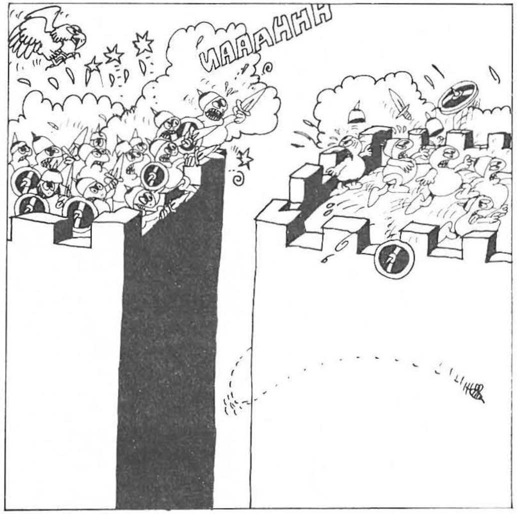


Fig. 47 The effects of electric force fields at a distance can be imagined something like this.

field forces, are also the reason that our capacitors act as accumulators of electrons.

If we arrange two metal plates at a distance and apply a number of electrons to the outside of one of the plates then they exercise a repulsive action on their like-charged compatriots on the other plate (Fig. 47). The second plate is thus depleted of electrons, if we have arranged that the electrons can flow away from it. This can occur, for example, by attaching the plate to a battery, as was done in Fig. 45. What happens now is that the negative pole of the battery transports electrons to one plate of the capacitor. The electrons on the opposite plate, that get displaced, flow to the electron-poor positive pole of the battery; they are attracted there by the opposite polarity. If the connection to the battery is broken in this condition then the capacitor remains charged; one plate possesses an excess of electrons and a corresponding number has disappeared from the other into the battery. The capacitor is charged; it has itself become a battery with an electron-rich negative pole and an electron-poor positive pole. The capacitor is storing a charge. If the two plates are connected to each other (e.g. via the loudspeaker), then the charges are equalized, the capacitor discharges and becomes neutral again.

What happens when the space between the two capacitor plates is filled with an insulator?

The capacitor is then able to store a larger charge, because the effects of the force do not have to be transmitted over the complete distance between the plates, but are transmitted from insulator atom to insulator atom.

How is this transmission to be explained?

The atoms of the insulator are deformed by the force of the electrical field, i.e. their electron shells are repelled by the capacitor plate with the excess negative charge. The atomic nucleus is no longer in the center of the electron shell. Such a deformed atom constitutes an electric **dipole**.

The ability of a capacitor to store electricity is known as its **capacity**. It is abbreviated to the letter **C** and is measured in farads F (after the English physicist Faraday 1791-1867) or millionths (μF = microfarad) or thousand millionths (nF = nanofarad) or million millionths (pF = picofarad) of a farady.

What does the storage capacity of a capacitor depend on?

a) On the size of the capacitor area (the thickness of a capacitor plate is unimportant, since the electrons exerting the force all sit on the surface).

b) On the distance between the plates of the capacitor.

c) On the substance between the plates, i.e. on the dielectric.

When these three conditions are incorporated into an equation then the following formula is obtained:

(F9) $$C = \varepsilon \cdot \frac{S}{d}$$

(capacitance of a plate capacitor)

The dielectric constant ε (lower case Greek epsilon) indicates, how much the capacity of a capacitor is increased over that of the same capacitor in vacuum by the introduction of the dielectric between the plates. Because of this ε is divided into two parts:

(F10) $$\varepsilon = \varepsilon_o \cdot \varepsilon_r$$

(dielectric constant)

Table 4 gives the value of ε for a variety of substances.

Table 4 Relative dielectric constants of various substances $_r =$

Material	ε_r
pressed paper	3.5 ... 4
press board	2.5
porcelain	5.4 ... 6.4
glass	3.4 ... 6
mica	5 ... 8
air	1.006

According to formula 9 the capacity of a capacitor increases as the area of the plates increases. The areas of the plates can also be increased by connecting capacitors in parallel.

$C_{tot} = C_1 + C_2$

If capacitors are connected in series then:

$$\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$$

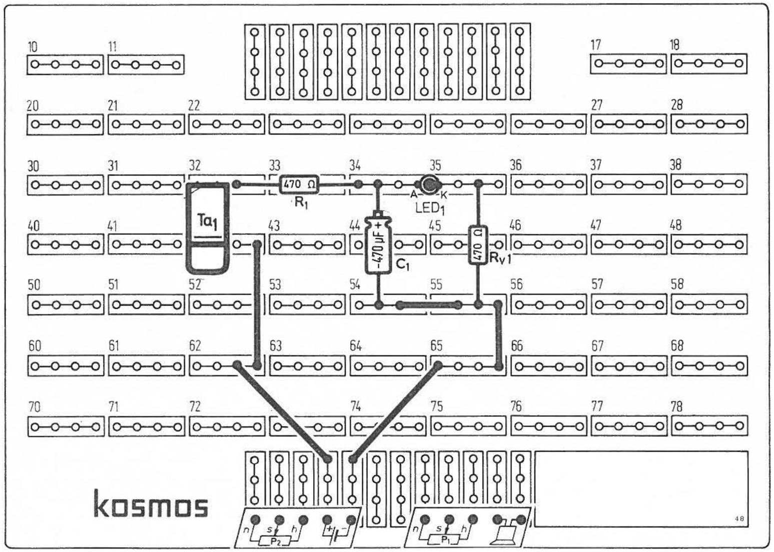

10
11
17
18
20
21
22
27
28
30
31
32
33
34
35
36
37
38
470 Ω
R1
A
K
LED1
Ta1
40
41
43
44
45
46
47
48
470 µF
C1
470 Ω
Rv1
50
51
52
53
54
55
56
57
58
60
61
62
63
64
65
66
67
68
70
71
72
74
75
76
77
78
kosmos
P2
P1

Fig. 48 Construction of circuit 49

8.2 Slow increases in potential

Alongside the remarkable properties of the capacitor that you have come to know from the previous section, there is yet another remarkable phenomenon, which occurs when capacitors and resistors work together.

Figure 48 illustrates an experimental arrangement; Fig. 49 is the corresponding circuit diagram. An investigation is to be made of the behavior of the electrolytic capacitor 470μF in conjunction with the 470-Ω-resistor $R1$.
When the contact maker is pressed, the LED only achieves its full brightness after a certain delay. When the contact maker is released (thus switching the battery out) then the LED is not extinguished immediately but decays over a certain period of time. So the interaction between the 470μF capacitor and the resistor $R1$ is evidently delayed both on charging and discharging.

You can try out capacitors of various sizes and change the value of $R1$.

Figures 50 and 51 show a graphical representation of the charging and discharging processes. It can be seen that the total charging or discharging time is divided into 5 time periods. The time period **T** (lower case Greek tau) is known as the time constant and is calculated as follows:

(F13) $\tau = R \cdot C$

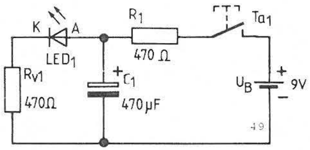

K
A
LED1
R1
470 Ω
Ta1
Rv1
470Ω
C1
470 µF
UB
9V
+
−
49

Fig. 49 Delay by capacitor and resistor

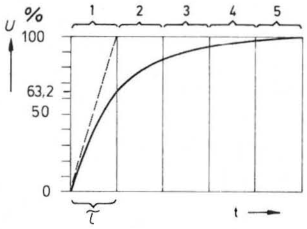


Fig. 50 Charging curve of a capacitor

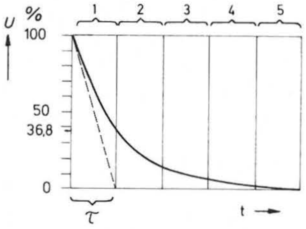


Fig. 51 Discharging curve of a capacitor

is independent of the battery potential and represents the time required to charge the capacitor potential to the extent of 63.2% of the battery potential; during the discharge process the charge on the capacitor has fallen to 36.8% of that of the battery potential after this period.

9. From semiconductor crystal to transistor

9.1 A special sort of conductivity

All metals conduct electrical current, we have already said that. It is important for us to know that their conductivity sinks as the temperature rises.

However some substances exhibit extraordinary behavior; they are insulators at room temperature, but begin to conduct electrical current as their temperature is increased. In contrast to the metals their conductivity increases with increasing temperature. Substances exhibiting this behavior are known as **semiconductors**. They include the elements silicon and germanium.

What causes this remarkable behavior?

Let us take the element silicon as an example. A crystal of silicon is made up of regularly arranged silicon atoms (a crystal lattice!). Each silicon atom possesses four electrons in its outermost electron shell. In the lattice every atom is bound to four neighboring atoms, whereby the four outer electrons provide the bonding, in that they alternately orbit the one and then the neighboring atom.

This interaction provides for powerful bonding. In order to imagine this process let us think of two children, who throw two balls backwards and forwards to one another. Together the children have a pair of balls and this forms a bond between them during the game.

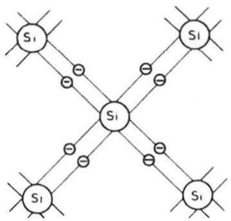


Fig. 52 Each Si atom is connected to its neighbors by four electron pairs.

Each silicon atom enters into four such electron pair bonds (Fig. 52). The difference from a metal is that the electrons in the outer shell of a semiconductor cannot migrate without further ado because of the powerful bond. At room temperature almost no current can flow through a crystal of silicon.

The introduction of energy, e.g. heat, releases some of the electrons from their bonding. They are available as "free electrons" and leave behind a vacancy, it is known as a "hole", which can be taken up by another electron.

9.2 A hole takes to travelling

If a heated crystal is subjected to an external electrical potential, then a current flows. The conduction process can be illustrated by means of the following sketch (Fig. 53).

A row of 6 mannikins transports round discs from left to right. However, the place where there is no disc migrates in the opposite direction.

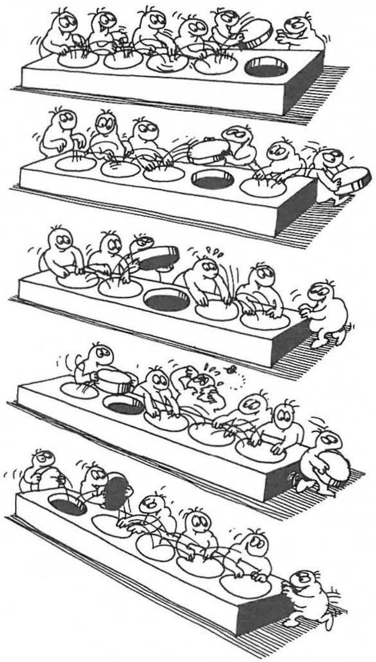


Fig. 53 The discs are transported from left to right; the hole migrates from right to left.

A similar process occurs during current conduction in semiconductors. The actual migration of electrons from negative to positive is accompanied by an apparent migration of "holes" from positive to negative. However, as already mentioned, all this only occurs at elevated temperatures.

9.3 Impurities desired

In order to be able to use a semiconductor at room temperature, without providing energy, it is necessary to increase the number of mobile electrons or of "holes". This is done by including atoms of other elements in the crystal lattice of silicon or of germanium. The inclusion of foreign atoms with five electrons in the outer shells increases the number of mobile electrons available, the inclusion of foreign atoms with only three electrons in the outer shell provides more places for electrons, that is holes (Fig. 54).

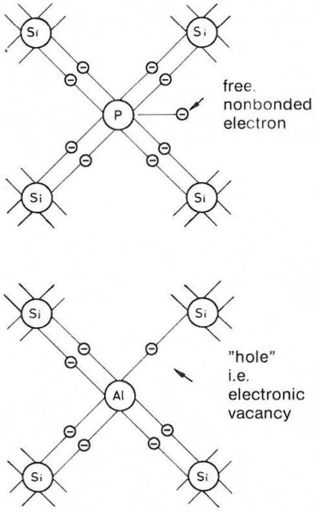


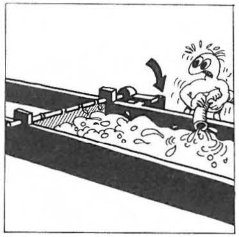
Fig. 54 The inclusion of various impurity atoms in a silicon crystal lattice (above phosphorus, below aluminum).

The process of including foreign atoms (or simply impurities) is known as **doping**.
If the number of available electrons has been increased then one speaks of **n material** and if the doping has produced free spaces for electrons ("holes"), then the result is known as **p material**.
Note:
The availability of electrons or of holes does not mean that the whole crystal has an external electric charge. This result is very important for the following treatment.

9.4 Diodes and pn junctions – one-way streets for electrons

A construction of n conducting and of p conducting materials is known as a diode; it only allows electrons to flow in one direction.
The principle of the flow and no-flow directions is illustrated in Figs. 55 and 56. What actually happens inside the diode is described in the following section without any mathematical ballast (Fig. series 57).

Fig. 55 "Water diode" (nonconducting state)



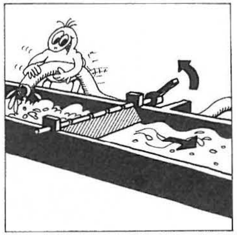
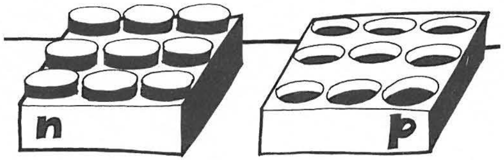
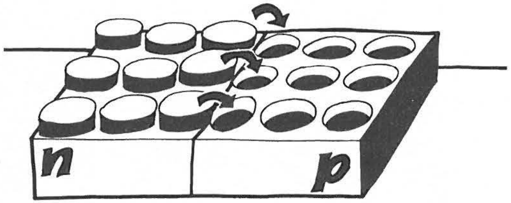


Fig. 56 "Water diode" (conducting state)

Fig. 57 The processes occurring inside a diode

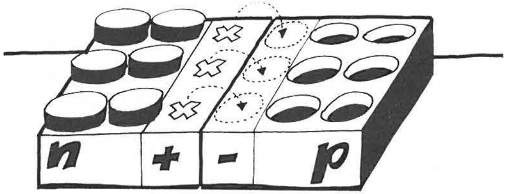


n Material contains free electrons, p material contains spaces for electrons ("holes").

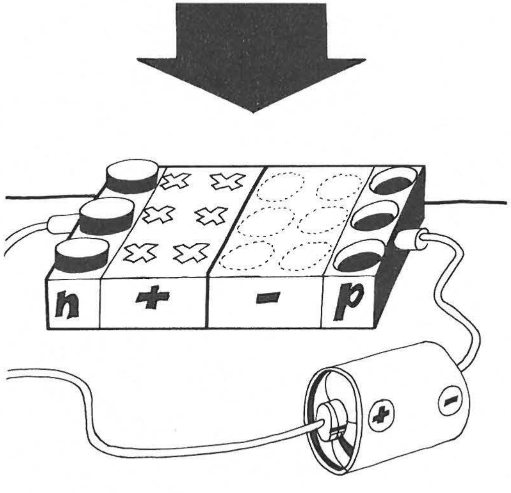


When n and p materials are brought together electrons in the boundary layer of the n material can migrate into the neighboring p material. This process is known as diffusion.

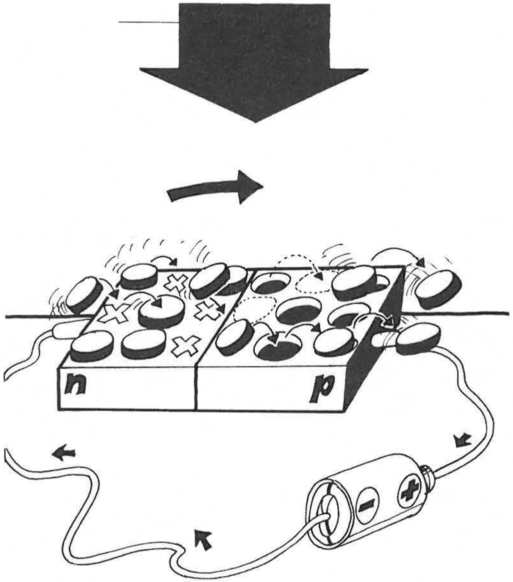
Diffusion has two important consequences:
1. The electrons that have diffused out of the n material occupy "holes" in the p material; this means that the boundary zone is depleted of mobile charge carriers.



2. The n material has donated electrons. It, therefore, acquires a positive charge. The p material has accepted electrons so it acquires a negative charge.



If an external potential is applied that is in the same sense as the internal potential (positive pole to the n and negative pole to the p material), then the zone of depletion is enlarged, current does not flow. The diode blocks the current.



If the external potential is reversed, so that it opposes the internal potential, then charge carriers migrate from outside into the depletion zone, current flows. The diode conducts.

9.5 Diodes on the test bed

The test involves the germanium diode, the silicon diode, the LEDs and the infrared diode. The test apparatus is the conduction tester from Section 3.3.

If you wish to know which of the diode connections is connected to the n conducting material (this connection is known as the **cathode**), then your test apparatus can give you the answer immediately. Attach the diode either way round to the wires coming from x and y; if the conduction tester makes a noise then the diode is connected in the conducting direction, i.e. the cathode (= n material) is at the y end. If the conduction tester remains silent then the cathode is at the x end and the diode is nonconducting so that no current flows.

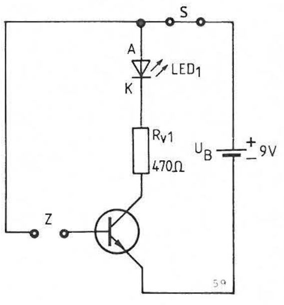


Fig. 59 Simple sensor contact

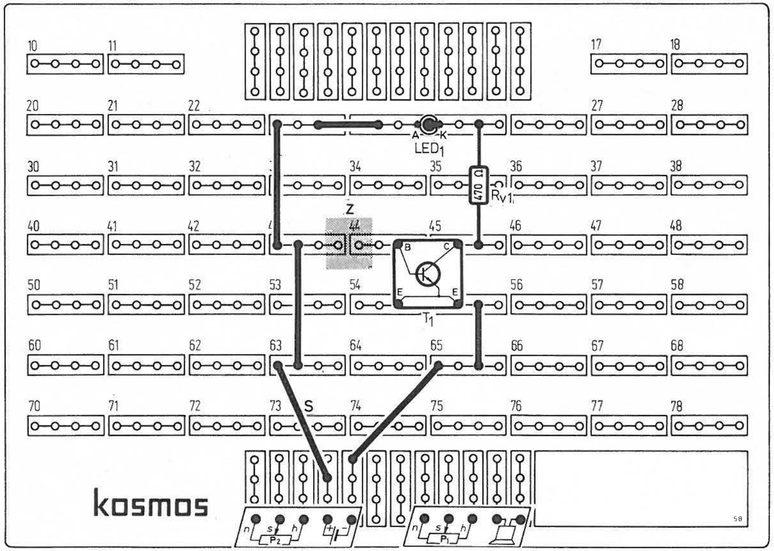


Fig. 58 Construction of circuit 59

9.6 The transistor – an amplifying element

The transistor is excellently adapted for the amplification of small currents. The principle is very simple. A small current is fed into a transistor and this causes a much larger current to flow, so that it can, for instance, power a LED. The relationship between the input current and the output current is known as **current gain**.

Current gain = output current/input current or expressed in another way:

(F14) $B=\frac{I_C}{I_B}$

The current gain of a transistor is characterized by the letter B. Figure 58 illustrates a very simple application of the principle. The current path is interrupted at the point z (circuit diagram 59). If you bridge the gap with a moistened finger a very weak and completely safe current of ca. 100μA flows through your finger into the transistor. The transistor greatly amplifies this tiny current. The output current is enough to light up the LED.

Contact B is known as the **base**, contact C as the **collector** and contact E as the **emitter**. What you experienced, as it were with your own body, with the contact switch can be very well explained in the following way.

In Fig. 61 in contrast to Fig. 60 you can see that a small stream of water flows through the base trough B, this raises a little flap just before flowing into the emitter bed. This flap is attached to the dam gate. The further the flap lifts the wider the dam gate is opened. The collector current from C, which flows into the emitter bed E, is many times greater than the amount of water in the base through coming from B. So the weak base current controls the strength of the collector current by means of this device. The current flowing out of

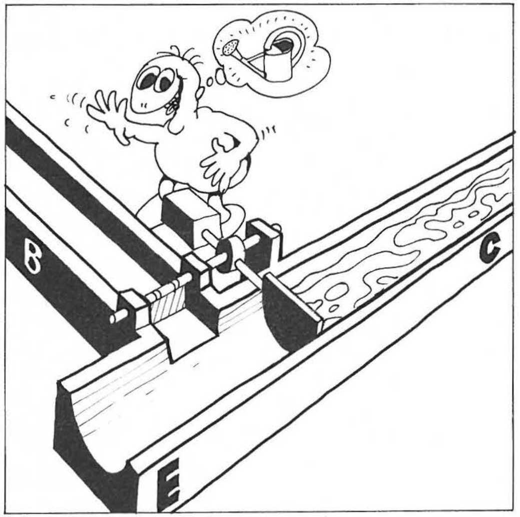


Fig. 60 "Water transistor" (nonconducting state)

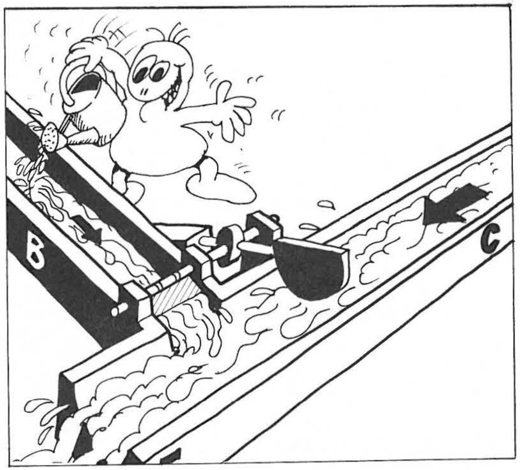


Fig. 61 "Water transistor" (conducting state)

the emitter bed at E is the sum of the strong collector current and the weak base current.

Like the diode the transistor is also a semiconductor device but, in contrast to the diode, it consists of three layers, which can, for example, be in the order n-p-n. Each of these layers has a connection. The base connection is made to the middle layer, the collector and the emitter are connected to the ends.

The Fig. series 62 alongside illustrates the process of conduction in the transistor.

In contrast to the water model we will describe the actual electron transport and not the conventional current direction. (The "block construction" of the various layers shown here for the sake of clarity is never employed in practice. A distinction is made between alloy transistors, diffusion transistors, drift transistors and planar transistors depending on the method of manufacture, which is sometimes extremely complex.)

p-n-p Transistors are also manufactured. All the explanations given here are also applicable to the p-n-p transistor, it is only necessary to change the polarities of all the potentials.

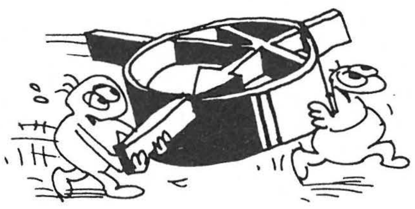
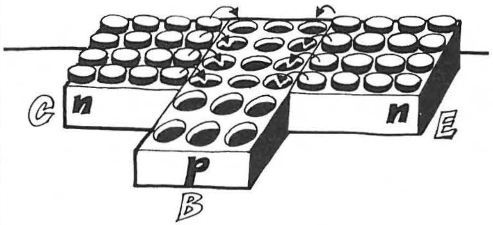
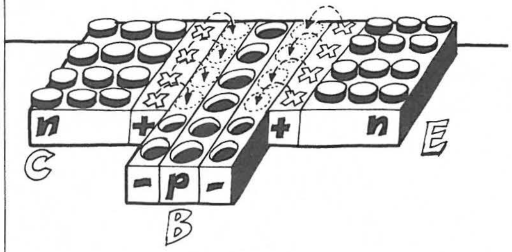


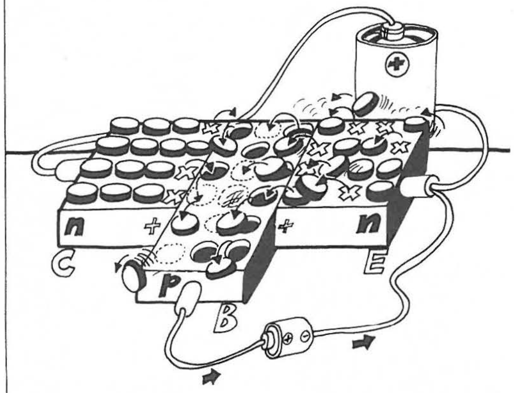
Fig. 62 The processes occurring inside a transistor



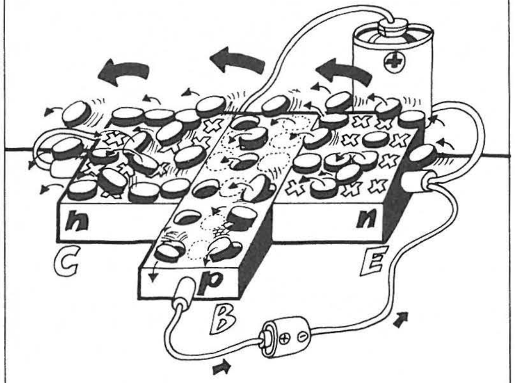
The layers are brought together. Diffusion processes occur.



Zones of depletion are formed, which extend well into the base. The n boundary layers become positively and the p boundary layers negatively charged (see diode).



Voltages are applied to the three connections so that they are in the opposite sense to the internal potentials. The emitter/base depletion zones disappear, because they are flooded with charge carries.



The player of the base is very thin; because of this the electrons penetrate into the collector depletion zone. The heavy collector current begins to flow.

10 Transistors in practice

10.1 A transistor tester

It is possible to regard a transistor in a rather simplified manner as two diodes connected back to back, as shown in Fig. 63.

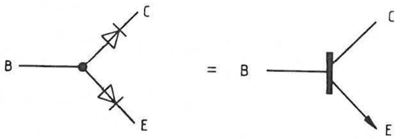
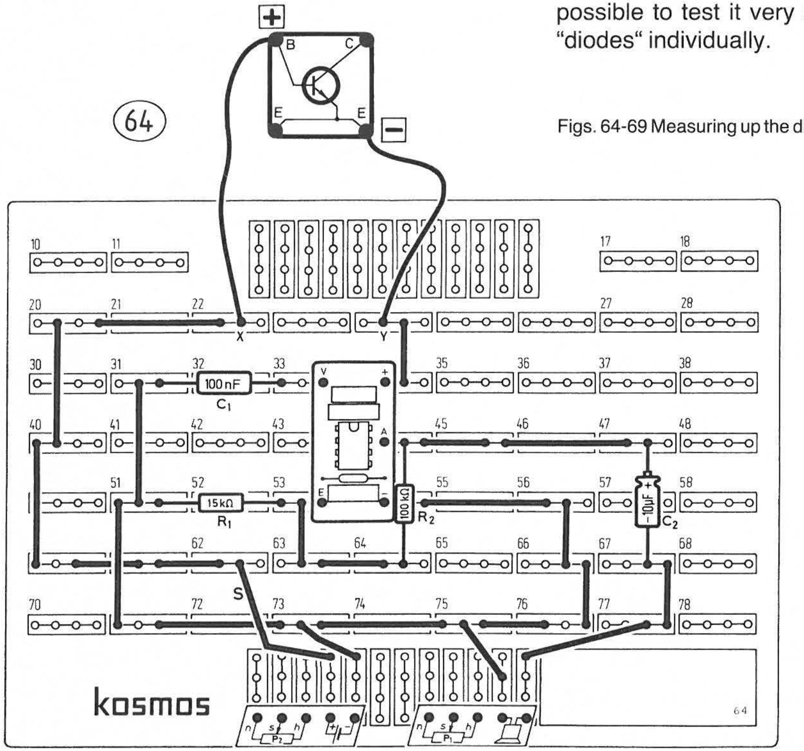


Fig. 63 Base-emitter and base-collector diodes of a transistor

If there is a suspicion that a transistor has for some reason or other given up the ghost then it is possible to test it very simply by testing its two “diodes“ individually.

Tests according to Figs. 64 and 65 must reveal conduction (conduction tester sounds a note), in Figs. 66 and 67 the diodes should be nonconducting (no note). Finally for certainty check that a test through both back to back “diodes“ does not

(64)


+
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B
C
E
E
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11
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18
20
21
22
27
28
X
Y
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33
35
36
37
38
100 nF
C1
V
+
40
41
42
43
A
45
46
47
48
51
52
53
E
55
56
57
58
15kΩ
R1
100kΩ
R2
10µF
C2
62
63
64
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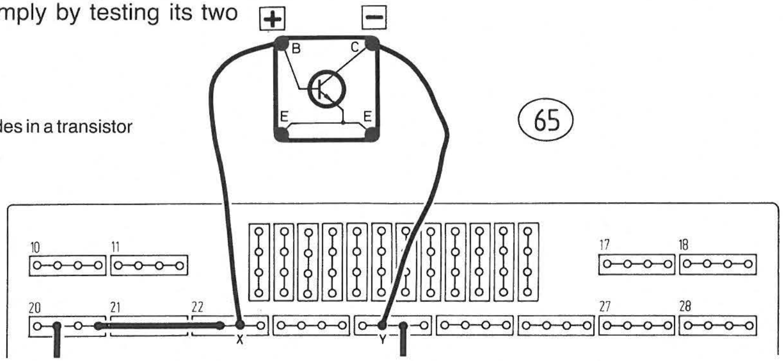
S
70
72
73
74
75
76
77
78
P2
P1
kosmos
64

(65)


+
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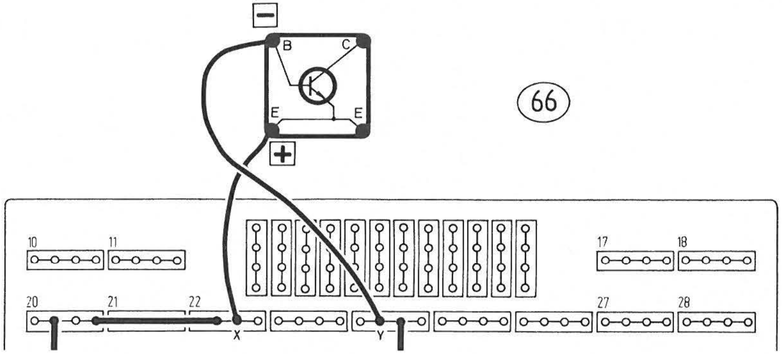
27
28
X
Y

(66)


−
+
B
C
E
E
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11
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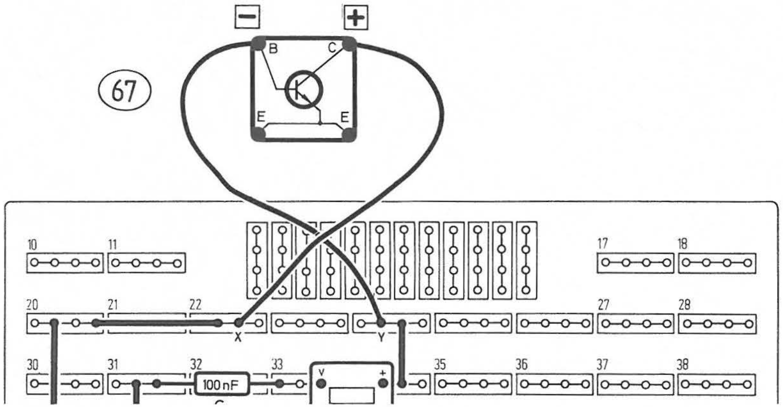
X
Y

Figs. 64-69 Measuring up the diodes in a transistor

(67)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X
Y
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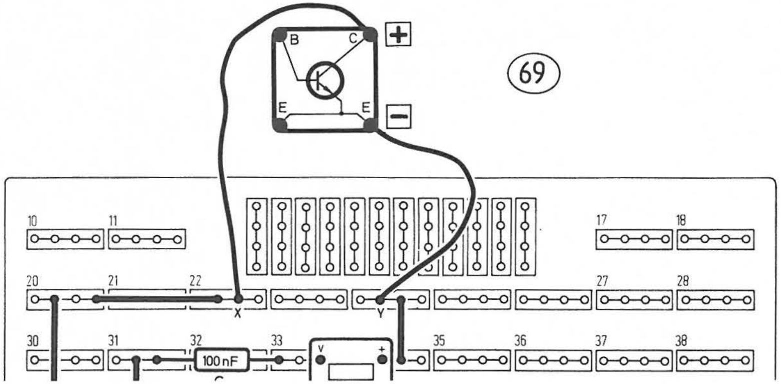
100 nF

(69)


+
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C
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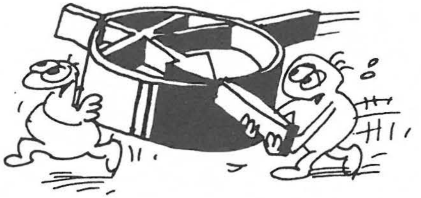
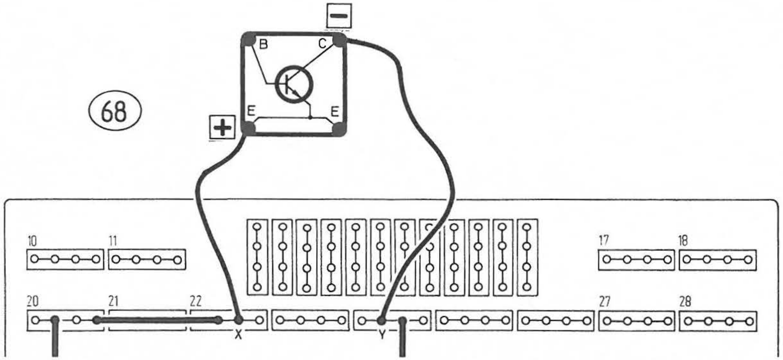
20
21
22
27
28
X
Y
30
31
32
33
35
36
37
38
100 nF

allow conduction either direction (Figs. 68 and 69). If the results of all these tests are positive then you can be sure that your transistor is still in working order. However, you do not get any information concerning the gain of the transistor or any other transistor data by this method.



(68)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X
Y

10.2 Dimmer circuit

We are now going to play the lock-keeper and introduce careful doses of current into the base trough of Fig. 61.

Remember the use of the potentiometer as a potential divider in Section 7.4 which you saw could be employed to create any potential between 0V and + 9V without any steps.

We will feed the potential output of the slide (via a protective resistor) to the base of the transistor, into the channel of whose collector a LED is inserted (it too is naturally provided with a protective resistor). Figure 70 shows the circuit diagram and Fig. 71 the construction diagram.

When the slide of the potentiometer is moved from n to h (adjustment knob from left to right), then the LED slowly begins to glow and gradually reaches its full power. That is what you would expect, because the gradually increasing potential drives an ever increasing current into the base of the transistor.

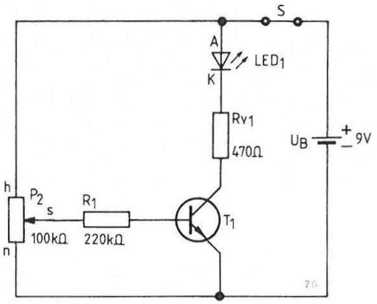

S
A
LED1
K
Rv1
470Ω
UB
+
9V
h
P2
s
R1
100kΩ
220kΩ
n
T1

Fig. 70 Dimmer circuit

10.3 Collector follower (common emitter connection)

A second transistor is provided for circuit 73 (construction 72) and now you will observe how the LED behaves when you turn the potentiometer switch from n to h. You will be able to confirm the following: If the switch is right down to n then T1 is nonconducting. So much current flows into the base of T2 via *R*2 that the LED is brightly illuminated. The more the knob is turned towards h the more T1 will conduct and it will claim an ever larger proportion of the current from *R*2 for itself – and thus the residual current available for the base of T2 will become ever smaller. The light-

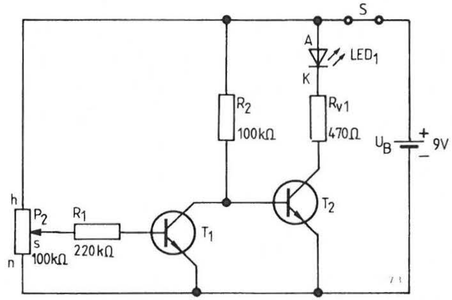
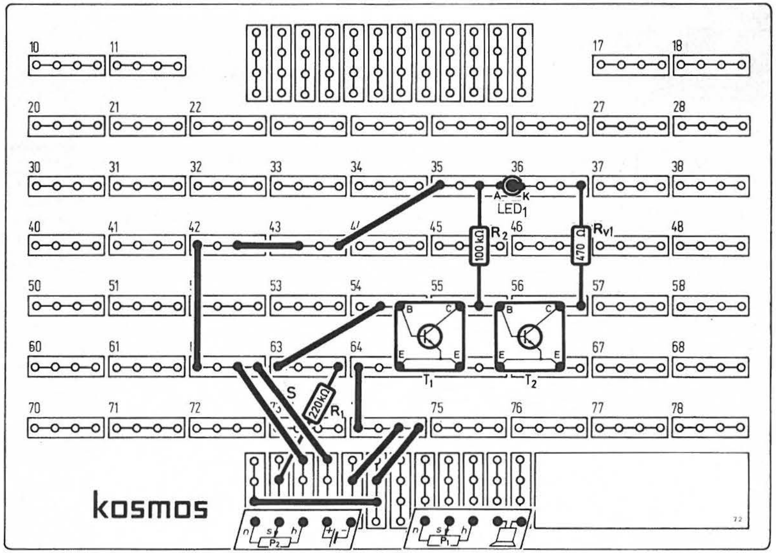

S
A
LED1
K
R2
100kΩ
Rv1
470Ω
UB
+
9V
h
P2
s
R1
100kΩ
220kΩ
n
T1
T2

Fig. 73 Light produces darkness

Fig. 71 Construction of circuit 70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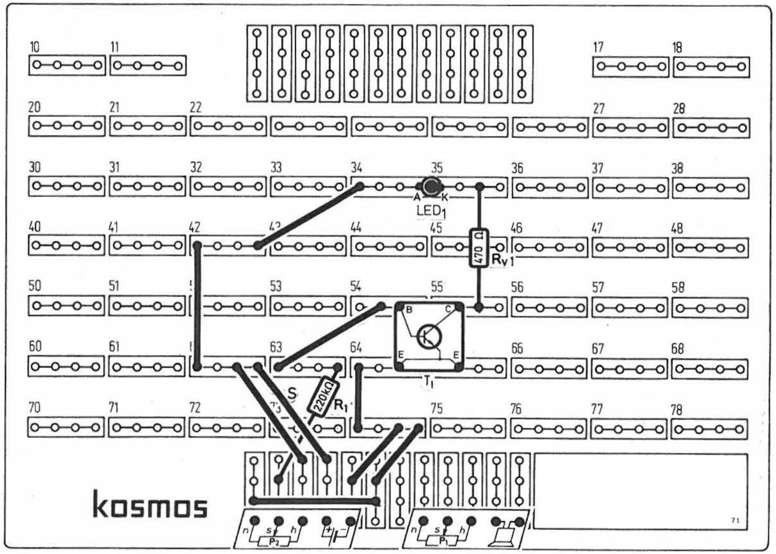
61
63
64
67
68
70
71
72
75
76
77
78
A
K
LED1
100kΩ
R2
470Ω
Rv1
B
C
E
T1
T2
S
220kΩ
R1
n
s
h
P2
P1
kosmos

Fig. 72 Construction of circuit 73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68
70
71
72
75
76
77
78
A
K
LED1
470Ω
Rv1
B
C
E
T1
S
220kΩ
R1
n
s
h
P2
P1
kosmos

emitting diode will rapidly darken and finally go out completely. It can also be viewed like this: The more conducting transistor T1 becomes the nearer the potential at its collecter approaches 0V. As a result the current flowing into the base of T2 decreases and with it the collector current of T2.

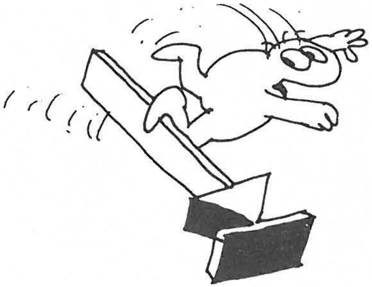
So you see the second transistor turns everything on its head so to speak. Light is made dark and dark is made light. This is known as inversion. A transistor whose emitter is connected to the ground of the circuit and whose working resistor is in the collector circuit acts as an inverter. This type of circuit is known as a common emitter connection or **collector follower**.

10.4 Emitter follower (common collector connection)

Nobody can forbid you to put the LED with its protective resistor in the emitter lead and to connect the collector lead of the transistor directly to the positive pole of the battery. Figure 75 shows such an arrangement. It is known as a common collector connection or **emitter follower**.

At first things function precisely as you remember from the common emitter connection; if the potential slide is moved from n to h then the LED gets brighter. However you will get a surprise when you add a second emitter follower as in circuit 76. No inversion takes place, the circuit behaves as if it consisted of a single transistor.

The explanation is simple. The emitter current of T1 flows directly into the base of T2. If the emitter current of T1 increases then the base of T2 receives more current and T2 becomes more strongly conducting.



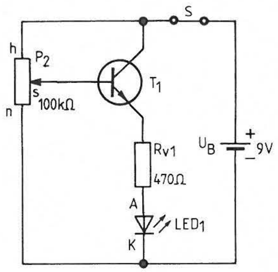
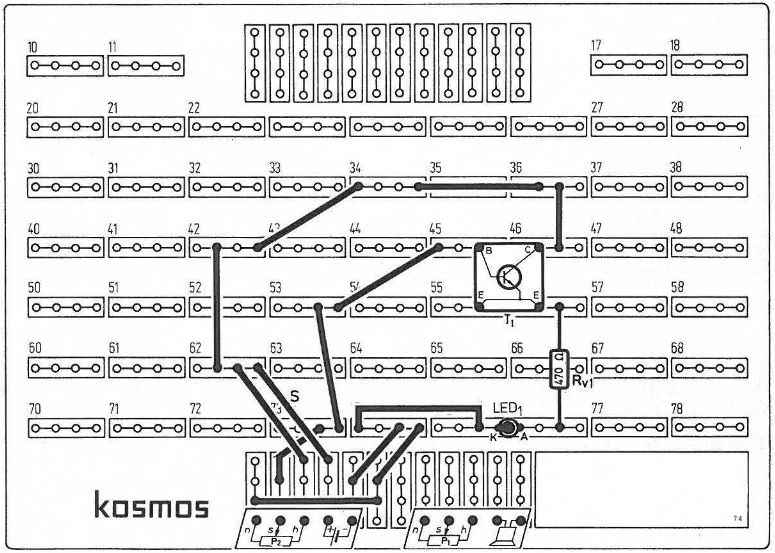

S
h
P2
s
100kΩ
n
T1
Rv1
470Ω
UB
+
9V
A
LED1
K

Fig. 75 Emitter follower

Fig. 74 Construction of circuit 75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62
63
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71
72
77
78
B
C
E
E
T1
470 Ω
Rv1
S
LED1
K
A
kosmos
n
s
h
P2
P1
74

10.5 The Darlington pair

The circuit shown in Fig. 76 (construction 77) is known as a Darlington amplifier or simply a **Darlington pair**. It is characterized by an immensely high current gain, which is the result of a multiplication of the current gains B1 and B2 of the two transistors. You will get an idea of it by taking out wire connector x whilst the LED is illuminated and then lightly touching contact clips 43 and 53 with a **dry** finger; the tiny current through the finger is so tremendously amplified that the LED immediately lights up.

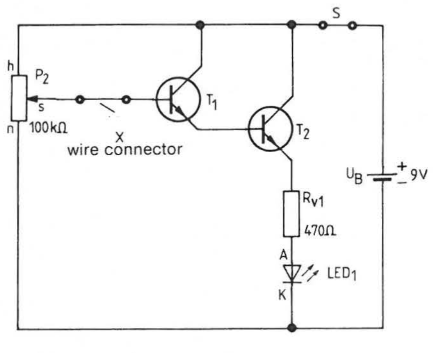
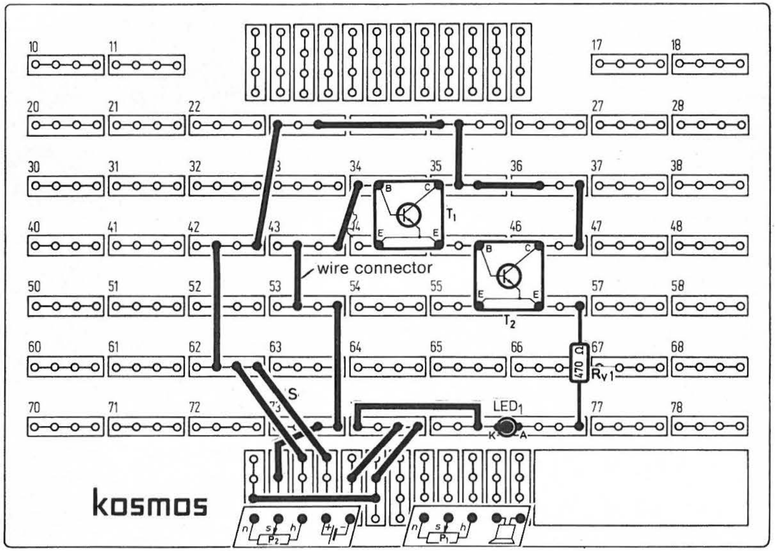

S
h
P2
s
n
100kΩ
x
wire connector
T1
T2
UB
+
−
9V
Rv1
470Ω
A
LED1
K

Fig. 76 Darlington pair

10.6 Electronic tapping

A variant of the Darlington pair is produced if the principle that the emitter current of the first transistor is led directly to the base of the second is retained but both collectors are connected together and work together against a resistor. For ease of understanding the Darlington pair is enclosed in a grey box in the circuit diagram for the finger morse practising apparatus (Fig. 78). Morse can be transmitted by tapping the morse code out lightly with the finger on contact clips 30 and 31.

Fig. 77 Construction of circuit 76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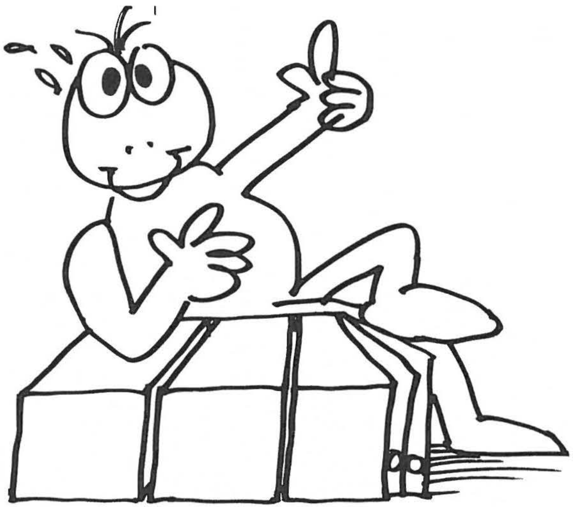
58
60
61
62
63
64
65
66
67
68
70
71
72
73
77
78
B
C
E
E
T1
T2
wire connector
S
470 Ω
Rv1
LED1
K
A
kosmos
n
s
h
P2
P1



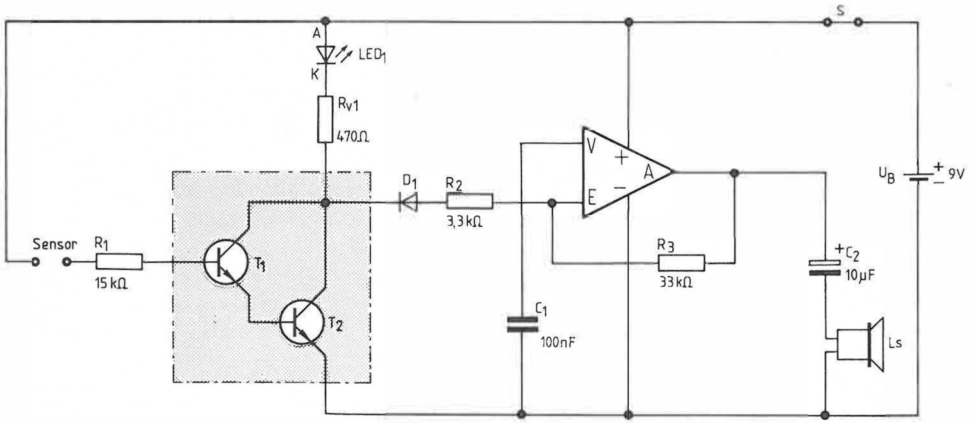
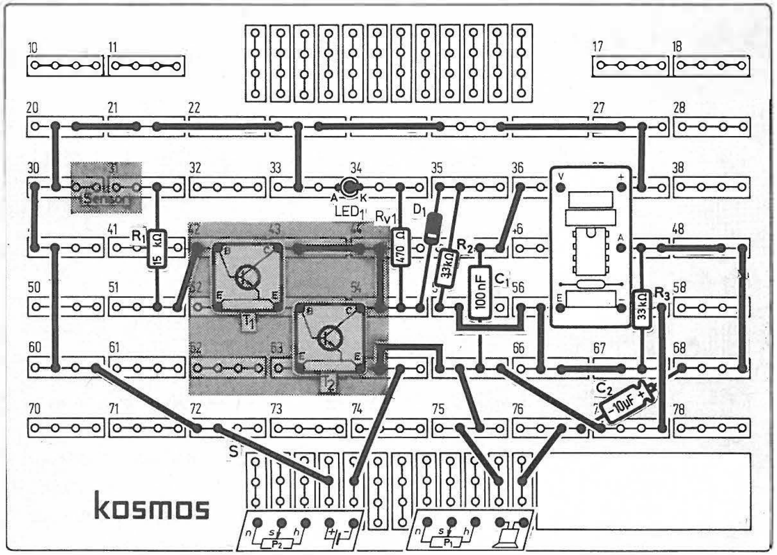

S
A
K
LED1
Rv1
470Ω
D1
R2
3,3kΩ
V
E
A
+
−
R3
33kΩ
UB
+ 9V
+C2
10µF
Ls
C1
100nF
Sensor
R1
15kΩ
T1
T2

Fig. 78 Finger morse practice unit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32
33
34
35
36
38
Sensor
LED1
Rv1
D1
41
R1
15kΩ
470Ω
R2
33kΩ
100nF
C1
56
48
R3
33kΩ
58
50
51
T1
T2
60
61
66
67
68
C2
10µF
70
71
72
73
74
75
76
78
S
kosmos
P2
P1

Fig. 79 Construction of circuit 78

11. Transistors as switches

11.1 Switches without contacts

It has already been mentioned briefly in Section 1.1 that mechanical switches with their contacts that are liable to wear often cause trouble. Electronics experts have always looked for ways of switching that are purely electronic – that is without mechanical movement. It was, therefore, obvious to employ a transistor as a switch, for we already know that a conducting transistor allows current to pass (from collector to emitter) like a closed switch and a nonconducting transistor acts like an open switch.

Whereas a mechanical switch is equipped with a lever to activate and deactivate, the transistor has its base for (electronic) activation. Before going on to the next section concerned with a variety of completely electronic switching circuits it must be emphasized that, even though it seems very elegant and tempting to replace a mechanical switch by a transistor, the disadvantages cannot be ignored. When a mechanical switch is in the closed state it is almost ideally conducting (the contact resistance only amounts to a few milliohms), with a conducting transistor, however, you have to accept the fact that with a conducting transistor there is always a residual potential between the collector and the emitter, this is known as the **residual collector- emitter potential** (ca. 0.3V for silicon transistors). In its nonconducting condition too the transistor is inferior to the (open) mechanical switch, which causes a 100% inter-

ruption of the circuit, while a very, very tiny but measurable current still passes through the transistor.
However we will ignore these facts in the section which follows and assume that the switching function of the transistor is ideal (or at least adequate).

11.2 Transistors in alternating step: Only one can conduct

A transistor with a common emitter connection (working resistance in the collector lead) inverts; a positive signal at the base makes it conduct, so that, put in a simplified manner, the collector is directly connected to the negative pole of the battery – thus the transistor switch is closed. If, however, the base is attached to the negative pole of the battery then the transistor ceases to conduct and the collector is at a positive potential – via the working resistor – a nonconducting transistor acts like an open switch. It can immediately be seen that a second transistor, whose base is connected to the collector of the first, must always be in the opposite state to the first: If the first is conducting the second must be nonconducting and if the first is nonconducting then the second must be conducting. This behavior has already been experimentally tested in Section 10.3; it is of decisive importance for the next circuits.

11.3 The flip-flop - a computer element

We are now going to discuss a computer element, that has become more famous than any other circuit; in electronic jargon it is known as a flip-flop, serious-minded people insist on calling it a **bistable multivibrator**.

There are thousands and millions of flip-flops in computer memories; they are, however, in the form of integrated circuits (IC) which can pack ten thousands of such flip-flops onto a single silicon chip a few millimeters square. Bi means two and hence a bistable element has two stable conditions. In circuit 81 either the left-hand or the right-hand transistor can be conducting, but never both of them at once.

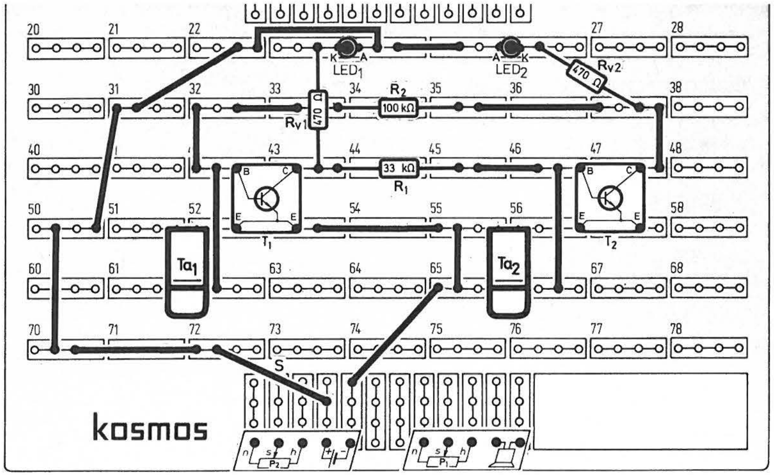


Fig. 80 Construction of circuit 81

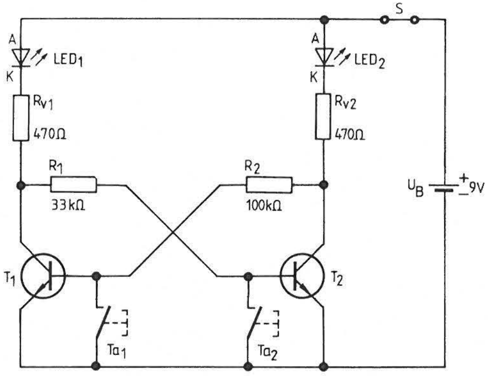


Fig. 81 The computer component known as a flip-flop

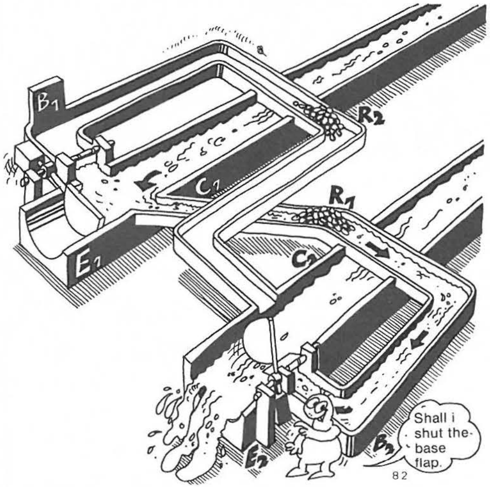

B1
R2
C1
R1
E1
C2
B2
E2
Shall i shut the base flap.
82

Fig. 82 Flip-flop model with a small problem – the water has to flow uphill!

The two possible states are, therefore, left-hand transistor conducting, right-hand transistor nonconducting or left-hand transistor nonconducting, right-hand transistor conducting. Since in each case the collector of one is connected to the base of the other there can be no change in the state taken up except because of an outside influence on the circuit.

You can now simulate an external signal by pressing contactors Ta1 and Ta2 alternately (construction 80) and thus connect either the base of T1 or of T2 with the negative pole of the battery; LED2 or LED1 then goes on or off depending on the original state of the circuit.

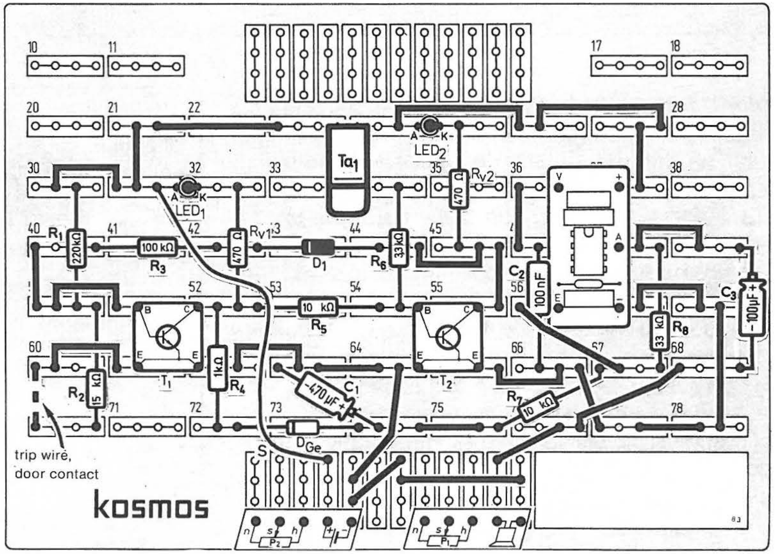
If you press once and then not again, then the condition taken up is maintained for eternity (or for as long as the circuit is supplied with current). What is it that can be stored then?

An "answer" for example; you can think of television programs where a group in the audience must act as judges by pressing a YES or a NO knob. Once the answer has been entered it remains visibly stored.

Electronic storage elements are also desirable in alarm systems; once the alarm has been given it is "remembered" until, for example, it is switched off by the owner of the alarm.

11.4 Sirens - for frightening burglars

The sophisticated alarm system in Fig. 83 does not give the burglar a chance. If the connection between contact clips 60 and 70 is broken (you can simulate the break-in by taking out the relevant wire connector; in practice a trip wire or a door or window contact would be employed instead of the wire connector), then the siren begins to wail. It can only be made to stop, when the contact between the two contact clips is restored **and** the resetting button is pressed and this can be very carefully hidden.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54
55
56
60
64
66
68
71
72
73
75
78
Ta1
LED1
LED2
R1
220kΩ
100 kΩ
R3
Rv1
470 Ω
D1
R6
3,3kΩ
Rv2
470 Ω
C2
100nF
R8
33 kΩ
C3
100µF
10 kΩ
R5
T1
T2
R2
15 kΩ
1kΩ
R4
470µF
C1
R7
10 kΩ
DGe
S
trip wire, door contact
kosmos
P2
P1
83

Fig. 83 Construction of circuit 84

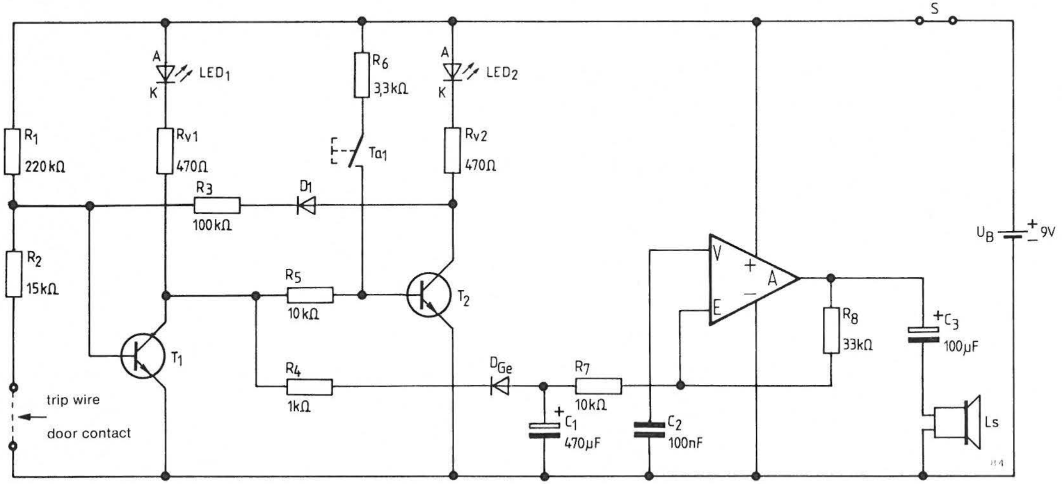

S
A
LED1
K
R6
3,3kΩ
A
LED2
K
R1
220kΩ
Rv1
470Ω
Ta1
Rv2
470Ω
R3
100kΩ
D1
R2
15kΩ
R5
10kΩ
T2
V
+
A
−
E
UB
+ 9V
R8
33kΩ
+C3
100µF
T1
R4
1kΩ
DGe
R7
10kΩ
+ C1
470µF
C2
100nF
Ls
trip wire
door contact

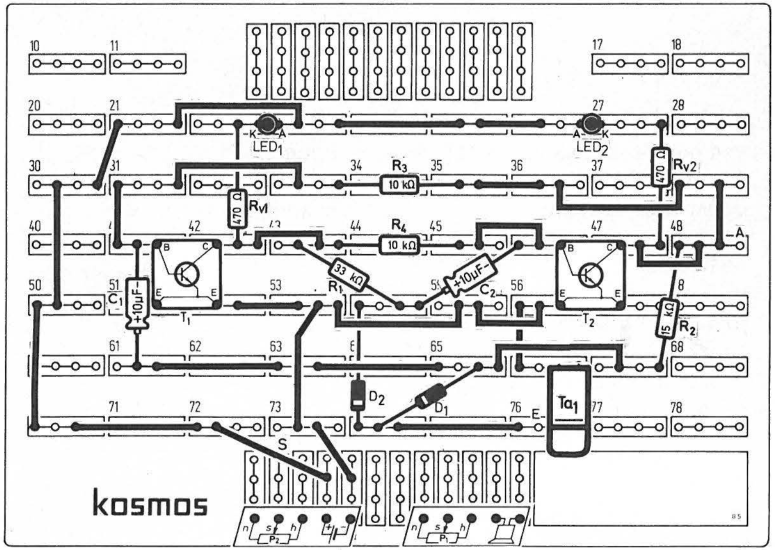
Fig. 84 Alarm unit – for frightening burglars

You will recognize the flip-flop at the left-hand side of circuit 84, although it has been slightly modified for the burglar alarm; resistance *R*1 together with diode D1 make sure that transistor T1 remains conducting (and hence the siren continues to wail) until the broken trip wire is mended and the reset is operated.

11.5 Electronic counting

Electronic counters (the specialist also calls them **digital counters**) contain a chain of special flip-flops, which we are now going to become acquainted with.

It can be seen in Fig. 86 that – as it should be in a flip-flop – the collector of one transistor is connected to the base of the other. But there are some changes compared with the simple flip-flop in Fig. 81; the two diodes are new as are the two electrolytic capacitors and the resistors *R*1 and *R*2. The astonishing thing is that one contact maker is sufficient in this circuit to switch the flip-flop to and fro; one press brings it into one condition, another press of the same contact maker then returns it to the original condition.
In order to understand this let us assume T1 is conducting and T2 nonconducting. *C*2 can then discharge itself via resistors *R*1 and *R*4, *C*1 in contrast charges via *R*2 and *R*v2 on the one hand and the base emitter diode on the other. The con-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21
27
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LED1
LED2
30
31
34
R3
10 kΩ
35
36
37
470 Ω
Rv2
40
42
44
R4
10 kΩ
45
47
48
A
470 Ω
Rv1
B
C
E
T1
33 kΩ
R1
+10µF
C2
50
51
C1
+10µF
53
56
T2
15 kΩ
R2
61
62
63
65
68
71
72
73
D2
D1
76
E
Ta1
77
78
S
kosmos
P2
P1

Fig. 85 Construction of circuit 86

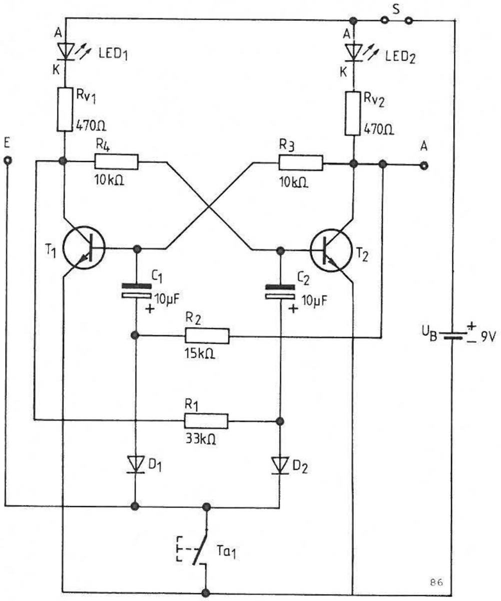


Fig. 86 Electronic change-over switch

tact maker is then pressed in this situation, so that the positive connections of the electrolytic capacitors are connected to the negative pole of the battery via diodes D1 and D2. This has no effect on *C*2, it simply remains discharged. *C*1, however, discharges, the connection that was originally positive has suddenly become negative via the contact maker and the diode. It is here that your knowledge of the effects of electrical forces at a distance on capacitors (see Section 8.1) is very useful: The electrons at the negative connection of the capacitor are displaced back to the base of the transistor and make it nonconducting (naturally because electrons have a negative charge!). This displacement effect because of the sudden discharge of a capacitor is known as an impulse and the specialist would say that T1 has been rendered nonconducting by a negative **impulse**.

Making T1 nonconducting sets the familiar flip-flop mechanism in action: T2 becomes conducting via *R*4 and *R*v1 and holds its partner transistor nonconducting via *R*3; the condition produced by the impulse thus remains stable. A glance at the two capacitors reveals that their charge states are now reversed, *C*1 has dischargerd via *R*2 and *R*3, *C*2, on the other hand, has become charged via *R*1 and *R*v1 and the base-emitter portion of T2. It does not require a great deal of imagination now to work out that pressing the contact maker once more would cause transistor T2 to become nonconducting and T1 to conduct.
Let us return to the electronic counter and replace the contactor switch in your imagination by a transistor switch. Figure 87 shows the circuit of an electronic counter that can count from 0 to 7. This requires three flip-flops. Each time the right-hand transistor in a flip-flop stage becomes conducting, it gives the left-hand transistor in the next stage a negative blocking impulse, which – as you know – causes this stage to switch over.
Figure 88 is a tabular representation of the eight states the flip-flops of the counter take when 8 negative impulses are applied to the input of the left-hand stage. If these "LED patterns" are correlated with the decimal digits from 0 to 7, then we have achieved what we set out to create, electronics that counts negative impulses.

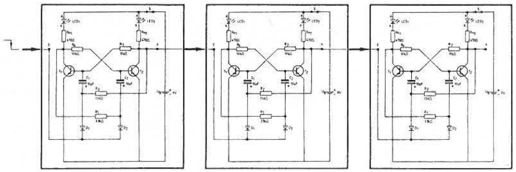


Fig. 87 Digital counter from 0 to 7 with three flip-flops

Impulse no.	LED1	LED2	LED3	Decimal no.
no impulse	●	●	●	0
first impulse	☼	●	●	1
second impulse	●	☼	●	2
third impulse	☼	☼	●	3
fourth impulse	●	●	☼	4
fifth impulse	☼	●	☼	5
sixth impulse	●	☼	☼	6
	☼	☼	☼	7
eighth impulse	●	●	●	(8)*

88

*the LED ofa fourth flip-flop would be necessary to represent the number 8

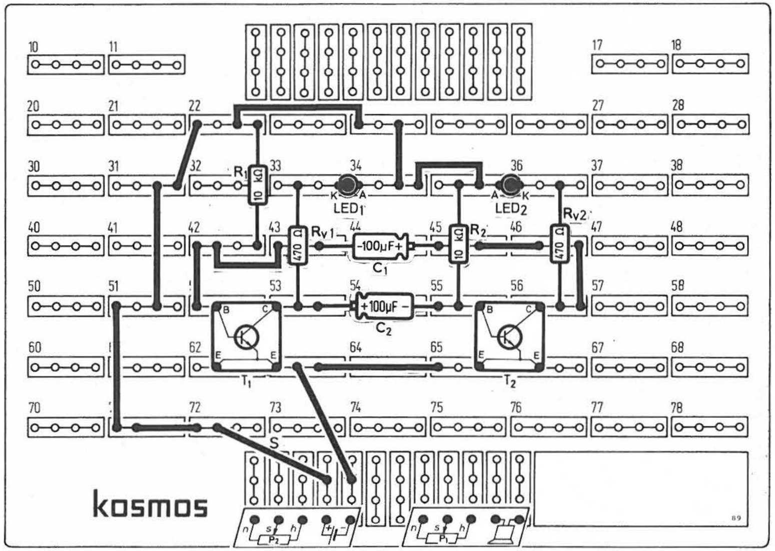
Fig. 88 State table for the digital counter in Fig. 87

11.6 Two transistors in an excitable state - the astable multivibrator

Almost everyone interested in electronics begins his or her career by building a blinker circuit. It is only later that these people find out that such a construction is known as an **astable multivibrator** (it is, in contrast to the flip-flop, a nonstable circuit), but only a few have the ambition to get to understand this fascinating phenomenon. Basically this is not very difficult to do if you understand the workings of capacitors and have grasped the explanation of the term "impulse" given in the last section.

The astable multivibrator (here in the form of a blinker circuit) is constructed according to Fig. 89. The two LEDs immediately give us a clear indication of the workings of the circuit: one transistor is always nonconducting and the other conducting, but they alternate continually without there being any intervention on your part.

Assume while looking at circuit diagram 90 that the left-hand transistor T1 is conducting and transistor T2 is nonconducting. Capacitor *C1* charges itself rapidly via the base-emitter diode of T1 and the resistor *Rv2* (low time constant because of the low ohmic value) and then maintains this charge for a period. However, something quite remarkable happens at *C2*; it charges slowly via the conducting transistor T1 and *R2*, but – and this will shock you – it is the wrong polarity for this charging process. But before you have to worry about your capacitor, you should observe what is happening at its negative connection. The saving moment occurs when the charging potential reaches ca. +0.6V; at this potential, which is also applied to the base of T2, this transistor begins to conduct. And now the electronic events begin to accelerate: the polarity of the potential at the collector of T2 changes from positive to negative, this change is transmitted as a negative impulse to the base of T2 via the charged capacitor *C1* when this converts to nonconduction. The relationships have now all inverted; *C1* charges rapidly and a slow charging process begins at *C2*. It does not take much imagination to visualize how this continual interaction can carry on to eter-



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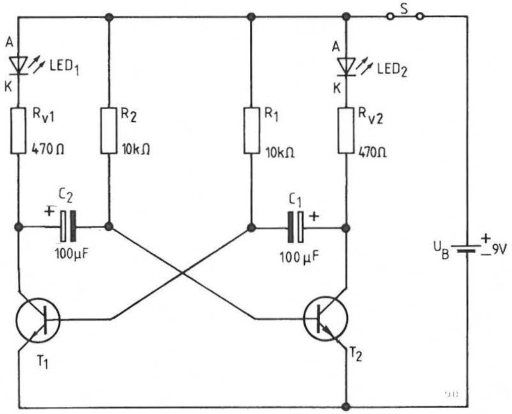
22
27
28
30
31
32
33
34
36
37
38
R1
10 kΩ
K
A
LED1
A
K
LED2
Rv2
40
41
42
43
44
45
46
47
48
470 Ω
Rv1
-100µF+
C1
R2
10 kΩ
470 Ω
50
51
53
54
55
56
57
58
+100µF -
C2
B
C
E
60
62
64
65
67
68
T1
T2
70
72
73
74
75
76
77
78
S
kosmos
P2
P1

Fig. 89 Construction of circuit 90



S
A
LED1
K
Rv1
470 Ω
R2
10kΩ
R1
10kΩ
A
LED2
K
Rv2
470Ω
C2
+
100µF
C1
+
100µF
UB
+
9V
T1
T2

Fig. 90 Astable multivibrator

nity – assuming of course that the current is not switched off. Moreover it is also already understandable that the rate of blinking is dependent on the charging time, that is on *C*1 and *R*1 or *C*2 and *R*2; large capacitors and resistors – low blinking rate; small capacitors and resistors – high blinking rate. (Try out various values).

11.7 Mr. Schmitt's trigger

A man called Schmitt once had a problem; he was asked by a computer manufacturer to design a potential monitoring system, that would set off an alarm, when the voltage supplied to the computer fell below a certain level – because... nothing upsets a computer freak more, than when he loses his program because the voltage drops. In order to take care of every risk, Mr. Schmitt was asked to make sure in addition that the alarm would only switch itself off when the voltage had climbed significantly again.
Nowadays, the circuit that Mr. Schmitt created is known as the **Schmitt trigger** in the electronics world and is extraordinarily valued by electronics specialists. It is employed for countless purposes as a limiting switch with **hysteresis** which in English means nothing more or less than that the potential thresholds for switching on and switching off are different. The circuit for such a trigger is shown in Fig. 92. You can try out the behavior of a Schmitt trigger with the construction in Fig 91, by slowly turning the potentiometer adjustment knob so that the LED illuminates and then carefully turning back to extinguish it. The settings of the knob for illuminating and extinguishing are astonishingly different!

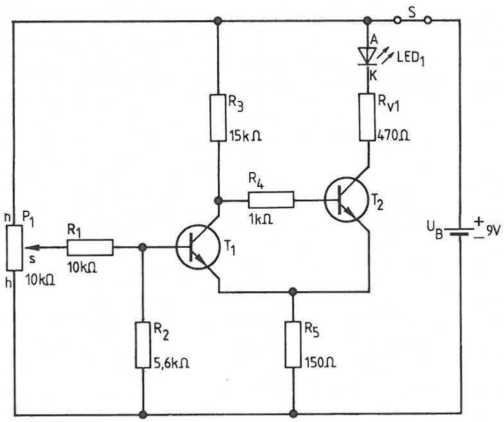

S
A
LED1
K
R3
15kΩ
Rv1
470Ω
R4
1kΩ
T2
T1
n
P1
s
h
10kΩ
R1
10kΩ
UB
+
9V
R2
5,6kΩ
R5
150Ω

Fig. 92 Schmitt trigger

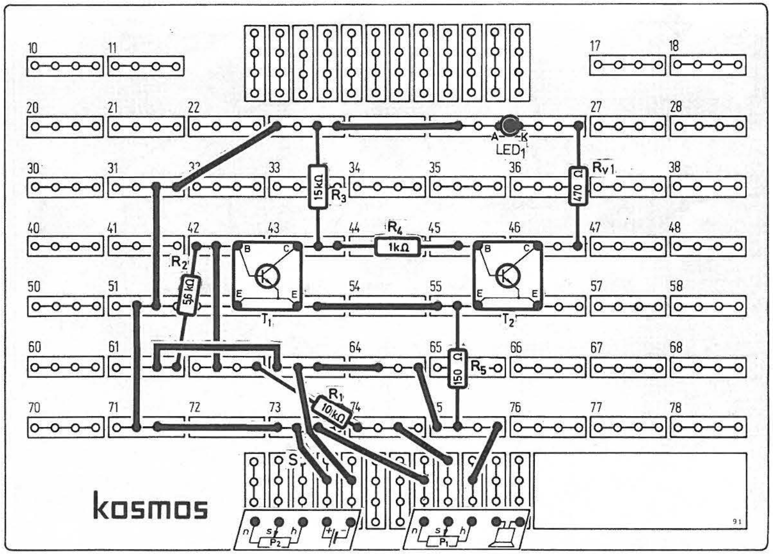
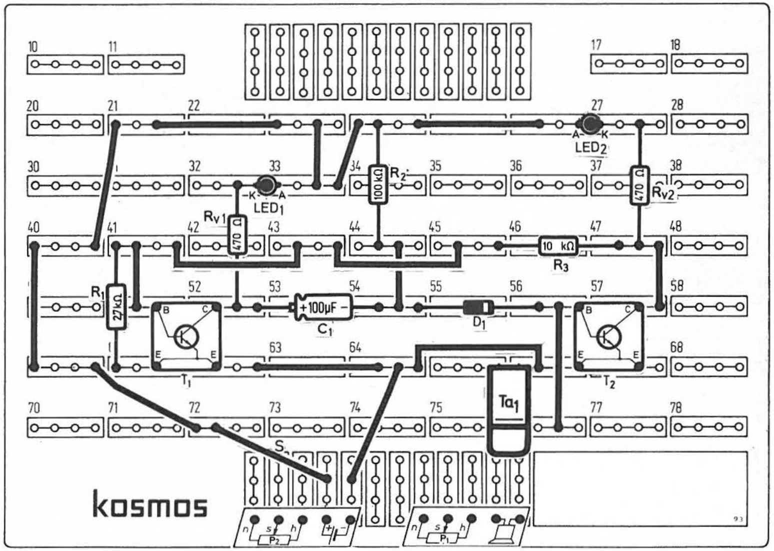

10
11
17
18
20
21
22
27
28
A
K
LED1
30
31
33
34
35
36
38
15kΩ
R3
470 Ω
Rv1
40
41
42
43
44
R4
45
46
47
48
1kΩ
R2
56 kΩ
B
C
E
T1
T2
50
51
54
55
57
58
60
61
64
65
66
67
68
150 Ω
R5
R1
10kΩ
70
71
72
73
74
75
76
77
78
S
n
s
h
P2
P1
kosmos

Fig. 91 Construction of circuit 92

11.8 Vibrations? No thank you! The mono-flop

Fig. 93 Construction of circuit 94


10
11
17
18
20
21
22
27
28
LED2
30
32
33
34
35
36
37
38
LED1
Rv1
470 Ω
100 kΩ
R2
470 Ω
Rv2
40
41
42
43
44
45
46
47
48
10 kΩ
R3
R1
2,7 kΩ
52
53
54
55
56
57
58
+100µF
C1
D1
B
C
E
T1
T2
63
64
68
Ta1
70
71
72
73
74
75
77
78
S
kosmos
P2
P1

The circuit known as the **monostable multivibrator**, or mono-flop for short, only executes a single oscillation, that is, goes for a certain time from a resting condition to an "active" condition and then returns after a certain time to the resting state. It is employed in practice as a timer; it is "flipped" by a negative impulse and switches on a LED (or any other apparatus, a siren, the staircase lights etc.); after a time they are automatically switched off.

In the construction in Fig. 93 the negative impulse is simulated by pressing the contact maker.

LED1 goes on and LED2 goes off for a period of about 10 seconds. Then nothing more happens until you press the contact maker again. Circuit diagram 94 provides information concerning the method of operation. Let us assume that LED1 is out, that is, T1 is nonconducting and T2 is conducting (LED2 is illuminated). As usual we have to consider what is happening to the capacitor; it is charged to the brim via *R*v1, on the one hand, and the base emitter diode on the other. Now briefly make T2 nonconducting (press the contact maker!). T1 now receives base current via *R*3 and *R*v2 and conducts, the potential at its collector changes instantaneously from positive to negative and a powerful negative impulse via the capacitor now continues to hold T2 in the nonconducting state, so that it is only necessary to press the contact maker for a split second. The capacitor now begins to charge via *R*2 and the conducting collector emitter path – again with the opposite polarity (see also the astable multivibrator)!

The potential on the right-hand side of the capacitor now increases slowly (the rate depends on the size of the capacitor and that of the resistor *R*1), until it reaches about 0.6V. At this level T2 becomes conducting and thus allows the base current for T1 to become exhausted: the original condition has been restored, the timed interval is over.

Experiment suggestion: You have seen that the timed interval depends on *C*1 and *R*2. It is possible by using various combinations of 15kΩ, 100kΩ and 220kΩ resistors with 100μF and 470μF capacitors to attain interval times of between almost one and twenty seconds.

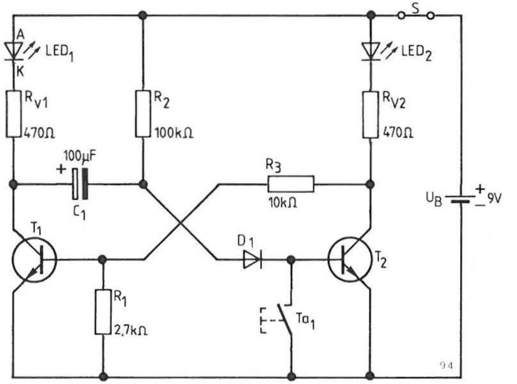

A
LED1
K
Rv1
470Ω
R2
100kΩ
LED2
Rv2
470Ω
S
100µF
+
C1
R3
10kΩ
UB
+
9V
T1
R1
2,7kΩ
D1
Ta1
T2

Fig. 94 Monostable multivibrator

We are now going to concern ourselves with completely electronic light, temperature, moisture and magnetism-sensitive switches as well as with lights which react to sound.

In each case a sensor is necessary which converts either light, temperature, humidity level, magnetism or sound into an electrical quantity.

11.9 Using light for switching

You have been provided with a phototransistor for switching with light; we will come back to this in detail in Section 14.

Since phototransistors and infrared diodes can, depending on the manufacturer, be very easily confused (and the IR diode, which we will discuss in detail later, does not emit any visible light), it is suggested that you first try out a small test experiment so that you can unequivocally distinguish the two components.

Insert the components one after the other into the layout according to Fig. 95, making sure that the **shorter pin** or lead runs to the contact clip **labelled C**. Direct a table lamp or flashlight **from above** on each of the components to be tested, in a darkened room; if the LED employed as a control lamp illuminates then the component is the phototransistor. This becomes conducting when it is illuminated and can now be identified permanently by means of a tiny fleck of paint on the side.

The phototransistor has no base connection and hence only two leads! In order to make it conduct it must be acted on externally by a "stream of light" ("photons"). The layout according to Fig. 96 is very impressive when it is first operated in a semi-darkened room. Adjust the potentiometer so that the indicator LED just goes out. If the room is not too dark you will be able to do this without difficulty. Then "aim" a flashlight at the phototransistor from above. When you score a "bull's-eye" the LED will illuminate immediately.

Now alter the amount of light in the room somew-

Fig. 95 Test circuit for phototransistor/IR diode

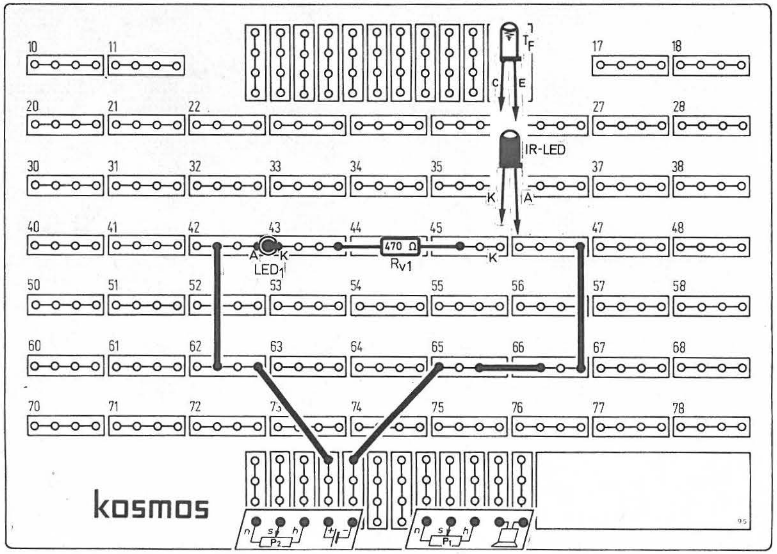
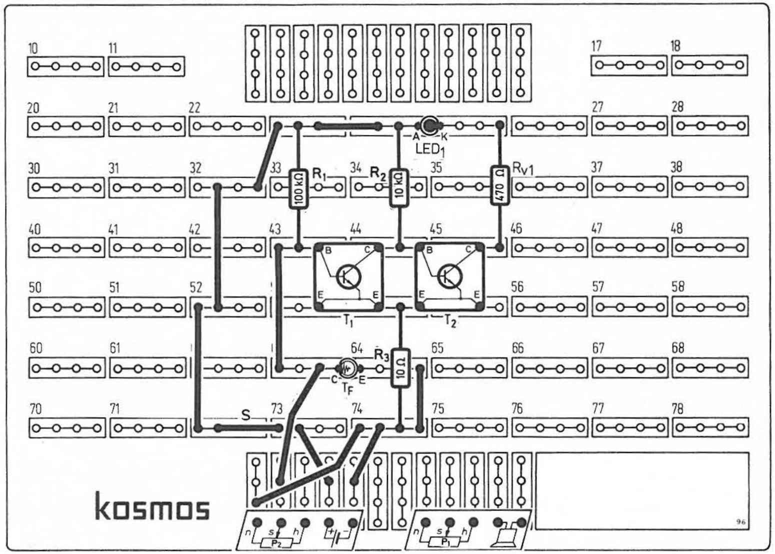


Fig. 96 Construction of circuit 97



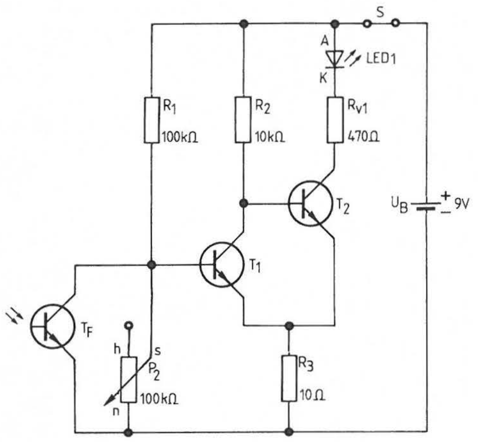

S
A
LED1
K
R1
100kΩ
R2
10kΩ
Rv1
470Ω
T2
UB
+ 9V
T1
TF
h
s
P2
100kΩ
n
R3
10Ω

Fig. 97 Light-operated switch

hat and play with P1 a little. You will find out that you can use the potentiometer to adapt the "switching threshold" to the light intensity.
Circuit 97 is very easy to understand, if you remember the inverting properties of collecter followers. When Tf is conducting T1 is nonconducting and thus T2 conducts (LED illuminated). On the other hand, if Tf is nonconducting T1 conducts while T2 does not conduct (LED out). What this experiment demonstrates very clearly is that switching processes can be set in motion without any moving contacts; we can assume that the working life of this electronic switch will be practically "infinite"!

11.10 Automatic night-light with Schmitt trigger behavior

Now let us reverse the function of the light-sensitive switch, so that the LED is illuminated when the surrounding light falls below a certain level. An automatic parking light for an automobile can be an example and that justifies the use of the Schmitt trigger; when it gets dark the parking light is to illuminate, but it must not go out immediately the moon peeps out from behind a cloud and casts some light on the phototransistor.
The apparatus is constructed according to Fig. 98, Fig. 99 shows the circuit diagram. T1 and T2 make up a Schmitt trigger, whose input potential is higher or lower depending on the conducting state of the phototransistor. The amplifier module that follows makes sure that the LED illuminates not with increasing but with decreasing light intensity (see Table 5).

Batteries still o.k.?

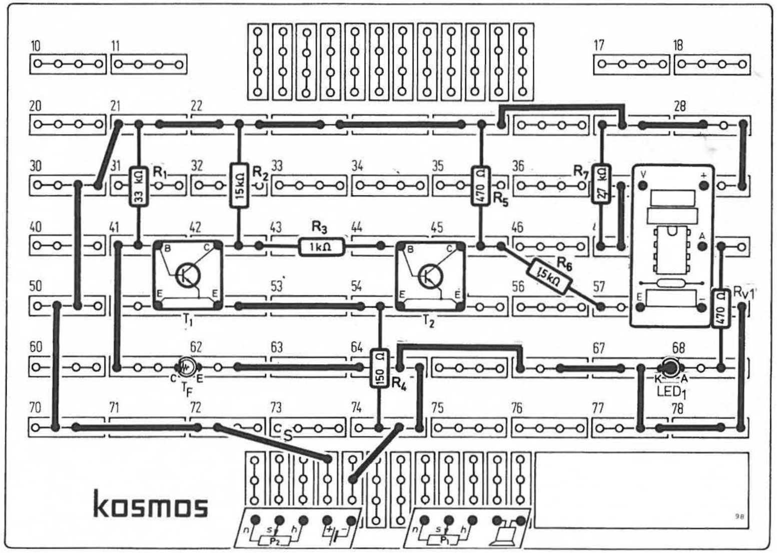

10
11
17
18
20
21
22
28
30
31
R1
33 kΩ
32
R2
15kΩ
C
33
34
35
470 Ω
R5
36
R7
27 kΩ
V
+
40
41
42
43
R3
1kΩ
44
45
46
R6
15kΩ
A
B
C
E
T1
50
53
54
T2
56
57
470 Ω
Rv1
60
62
C
E
TF
63
64
150 Ω
R4
67
68
K
A
LED1
70
71
72
73
CS
74
75
76
77
78
kosmos
n
s
h
P2
P1

Fig. 98 Construction of circuit 99

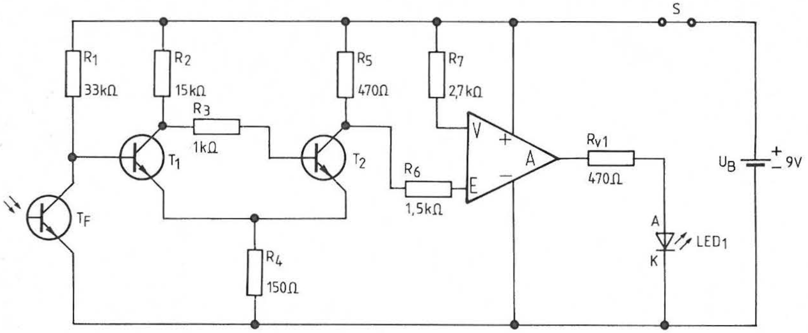
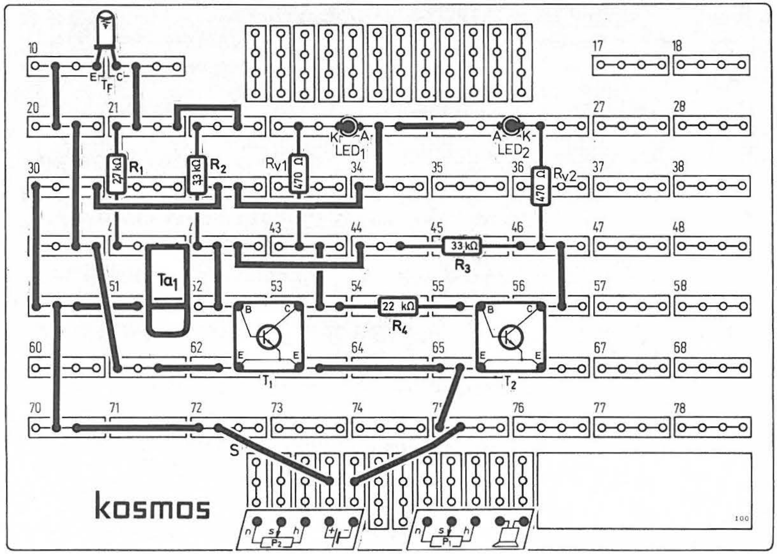
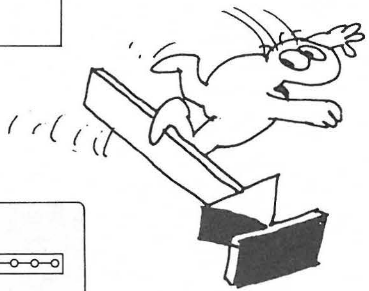

S
R1
33kΩ
R2
15kΩ
R3
1kΩ
R5
470Ω
R7
2,7kΩ
T1
T2
R6
1,5kΩ
V
+
A
E
−
Rv1
470Ω
UB
+
9V
A
LED1
K
TF
R4
150Ω

Fig. 99 Automatic night-light

Fig. 100 Construction of circuit 101


10
E
C
TF
17
18
20
21
27
28
K
A
LED1
A
K
LED2
30
27kΩ
R1
33kΩ
R2
Rv1
470 Ω
34
35
36
470 Ω
Rv2
37
38
43
44
45
33 kΩ
R3
46
47
48
Ta1
51
52
53
54
22 kΩ
R4
55
56
57
58
B
C
E
E
T1
T2
60
62
64
65
67
68
70
71
72
73
74
75
76
77
78
S
kosmos
n
s
h
P2
P1
100



11.11 More safety on the road - an automatic headlight dipper

The sad rate of automobile accidents would be considerably reduced if autos were fitted with an automatic electronic system, that dipped the headlights immediately a vehicle came from the opposite direction. The following circuit is especially dedicated to the traffic control authorities. Figure 100 illustrates its construction, Fig. 101 is the circuit diagram. When the contact maker is pressed the LED, which represents the headlights, is illuminated. When the light falls on the phototransistor (we have enclosed it in a little tube of black card for a realistic simulation), then T1 begins to conduct and the flip-flop flips; the headlight goes out and in its place the control light goes on.

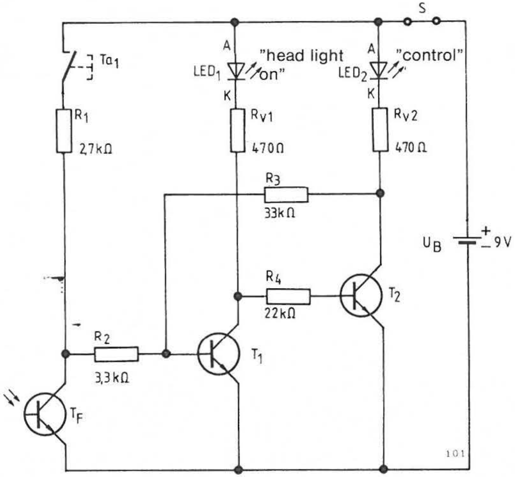

S
Ta1
A
LED1
K
"head light "on"
A
LED2
K
"control"
R1
2,7kΩ
Rv1
470Ω
Rv2
470Ω
R3
33kΩ
UB
+
9V
R4
22kΩ
T2
R2
3,3kΩ
T1
TF
101

Fig. 101 Automatic headlight dipper

11.12 Heat switches on a noise

Fire alarms fulfil an important role in real life. The regulations require them in department stores, public rooms, movie theaters etc; when the temperature rises above a certain level, they switch on the sprinkler systems automatically.

Our contact-less thermal switch in Fig. 102 will not switch on floods of water but it will set off a warning sound that cannot be missed. The thermal sensor is transistor T1 which, together with T2, makes up what is known as a current compensating circuit.

Fig. 103 Fire alarm

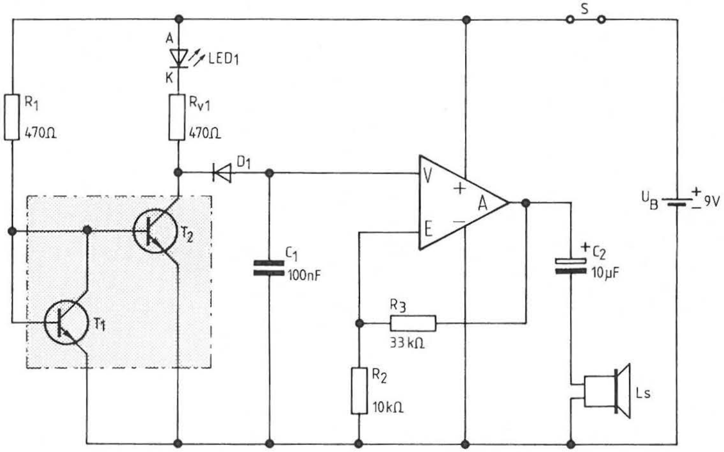
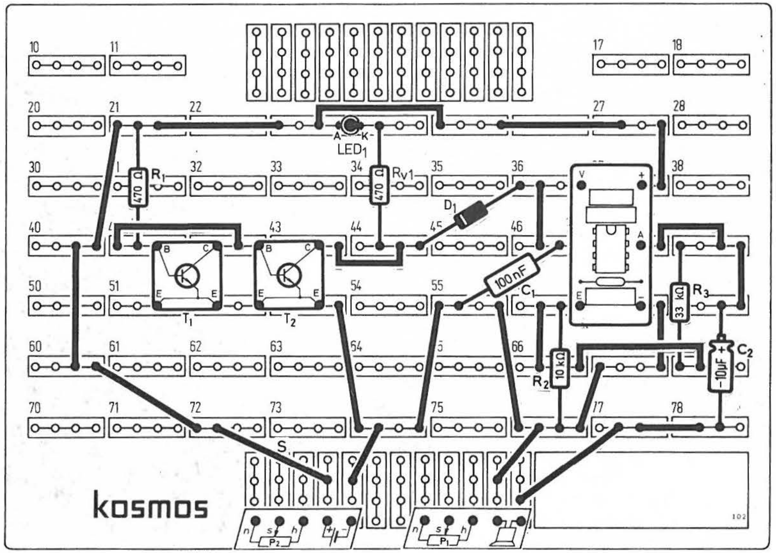

S
A
LED1
K
R1
470Ω
Rv1
470Ω
D1
V
+
A
E
−
UB
+
−
9V
T2
T1
C1
100nF
+C2
10µF
R3
33kΩ
R2
10kΩ
Ls

Fig. 102 Construction of circuit 103


10
11
17
18
20
21
22
27
28
30
32
33
34
35
36
38
40
43
44
46
50
51
54
55
60
61
62
63
64
66
70
71
72
73
75
77
78
LED1
A
K
R1
470 Ω
Rv1
470 Ω
D1
B
C
E
T1
T2
100nF
C1
V
A
33 kΩ
R3
10 kΩ
R2
10µF
C2
S
kosmos
P2
P1
102

11.13 How can an electronic circuit sense the temperature?

The properties of every electronic component alter as the temperature changes. The alterations are often so small that they do not have any appreciable effect on the functioning of the circuit. Sometimes, however, it is necessary to take countermeasures in order to compensate for temperature effects.

The base-emitter potential of a normal transistor falls by almost 3 millivolts per degree celsius. This does not seem very much, but it has an effect on the base current (the base current increases), whose temperature-dependent change is reflected in a considerable increase in the collector current. This can lead to nasty complications in amplification applications.

11.14 Stabilization by compensation

Current compensation is applied particularly in operational amplifier technology (operational amplifier see KOSMOS X4000, Section 17 of this book) in order to temperature-stabilize high gain transistor circuits. Figure 104 shows a simplified version of a current compensating circuit, as it is employed in our temperature warning apparatus (specially marked in circuit diagram 103). If both transistors are arranged so that they always have exactly the same temperature (they are then said to be thermally coupled), then the current through *R*2 remains practically constant, since it is the "mirror image" of the current through *R*1 because of the simultaneous reduction of the base-emitter potentials of T1 and T2.

The situation develops quite differently if, for example, only the left- hand transistor is heated. Then it is only its base-emitter potential that drops and this causes the right-hand transistor to cease conducting: its collector potential rises and sets off the alarm via diode D1.

The whole process naturally occurs in the opposite direction on cooling a transistor. We will exploit this in the "ice warner" and "cooling monitor" circuits.

If you test values of 470Ω, 1kΩ and 1.5kΩ for *R*1 you will see that as the resistance increases so does the sensitivity of the circuit. If a "good" transistor pair has been employed the circuit with *R*1 = 1.5kΩ reacts if you breathe on T1 or warm it with the tip of your finger.

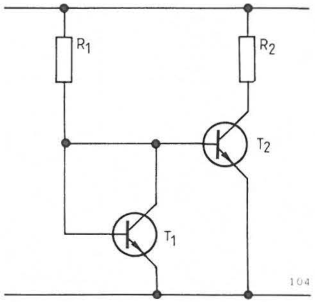
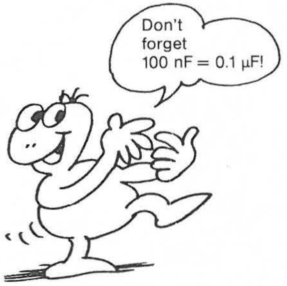


Fig. 104 Principle of current compensation

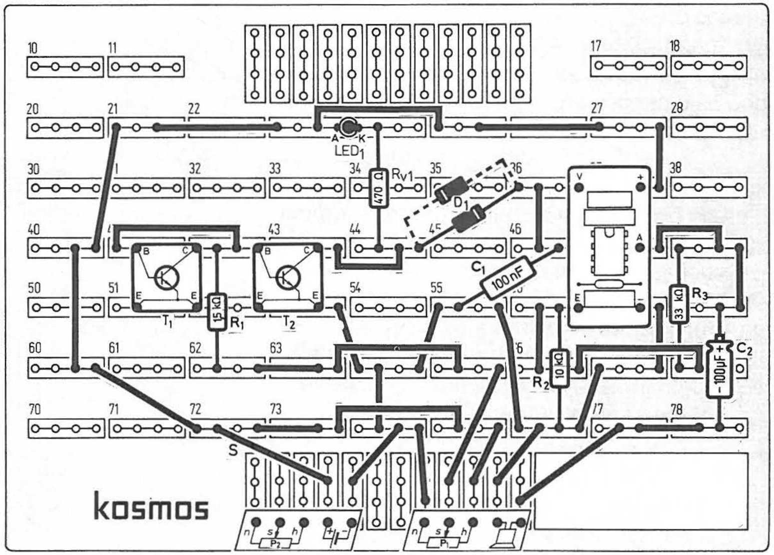

Don't forget 100 nF = 0.1 µF!

11.15 Very sensitive to cold – the ice warner

It is every driver's nightmare – the borderline between freezing and thawing, when the outdoor temperature is about zero. In order to make driving more relaxing an electronic circuit can be employed to give a warning signal when the thermometer falls under – say – plus three degrees celsius.

Rebuild the temperature switch according to construction diagram 105 (circuit diagram 106). The potentiometer, with which the circuit can be adju-

Fig. 105 Construction of circuit 106



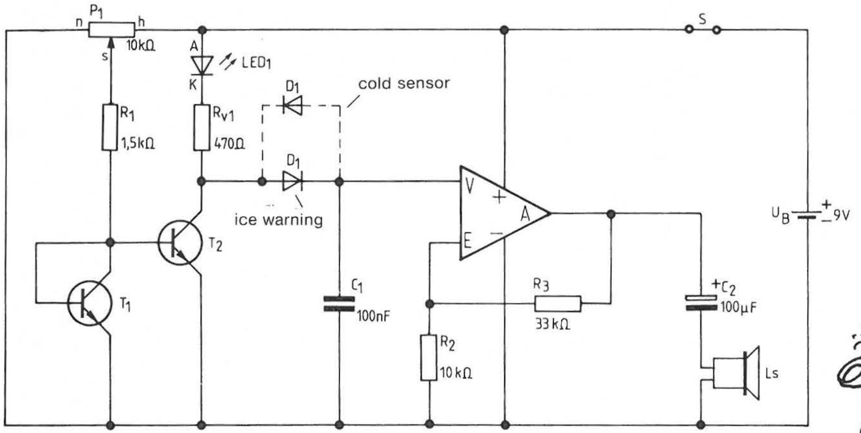


Fig. 106 Ice warning/cold monitor

sted as to at what temperature it reacts, is a new addition.

How can the apparatus be calibrated to zero degrees Celsius? If you do not wish to employ expensive thermometers and complicated measurements there is only one way. That is to dip the temperature sensor, i.e. transistor T1, in ice water (water with ice cubes floating in it). This can be done by removing the transistor module from the plug board and wrapping extension leads round its connections; these leads are then attached to the plug board and the transistor can be carefully dipped "head downwards" in the ice water, without immersing the transistor connections (water has a certain conductivity and would set up a circuit between the connections!). It is true that the whole process is rather awkward, but we have performed it successfully and it really works. The transistor should be immersed in the ice water for a period then the potentiometer should be so adjusted that the warning is just given. The likelihood is now very great that the triggering temperature is a few degrees above zero.

11.16 Frosty watchdog: electronics guards the freezer

If the ice warning is stood on its head you get a cold monitor. What is meant is that a cold monitor has to spring into action when the temperature rises. To this extent it possesses the same function as the temperature switch, but here the trigger temperature can be adjusted by means of the potentiometer. Remove diode D1 in construction diagram 105 and re-insert it in the plug board the opposite way round – done! How can the function of the device be tested?

The transistor T1 employed as a temperature sensor can be inserted in the second plug board and connected to the device by means of extension leads. The complete second board must then be placed in the freezer or the ice compartment of the refrigerator. The potentiometer can then be adjusted to give the desired triggering temperature of the cold monitoring alarm (the device can be tested by spraying the transistor with a "cold spray" obtainable from electronics dealers).

11.17 Is a transistor magnetic?

Of course not and if you want to construct a magnetically activated switch you will have to arrange that the magnetic force is converted into an electrical current. That is easy to do. All you need are a coil and a permanent magnet (both are to be found in the "KOSMOS Electro Tech" kit). Attach the coil to the base of T2 in layout 107 and drop the magnet into the coil. If the magnet is the right way round the circuit will respond and the LED is illuminated.

(If it is already on when the circuit is switched on then the contact maker must be momentarily depressed.)

You will recognize the good old flip-flop circuit from Section 11.3 in circuit diagram 108, however, here the base of T2 is attached to the coil.

What happens when a coil is moved in a magnetic field or vice versa? A potential is induced in the coil (you will learn about the concept of induction in Section 12.3). Depending on which magnetic pole is below or above when a magnet is allowed to fall into the coil the base experiences either a negative or a positive potential impulse. Our circuit only reacts to negative impulses, because transistor T2 then becomes nonconducting for an instant. The original state can be attained once more by pressing the contact maker briefly.

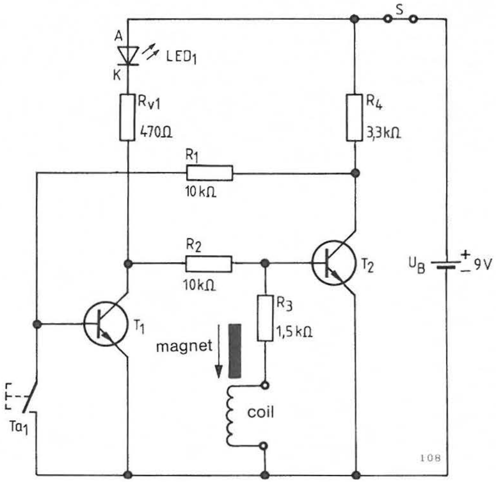

S
A
LED1
K
Rv1
470Ω
R4
3,3kΩ
R1
10kΩ
R2
10kΩ
T2
UB
9V
T1
R3
1,5kΩ
magnet
coil
Ta1
108

Fig. 108 Magnetically operated switch

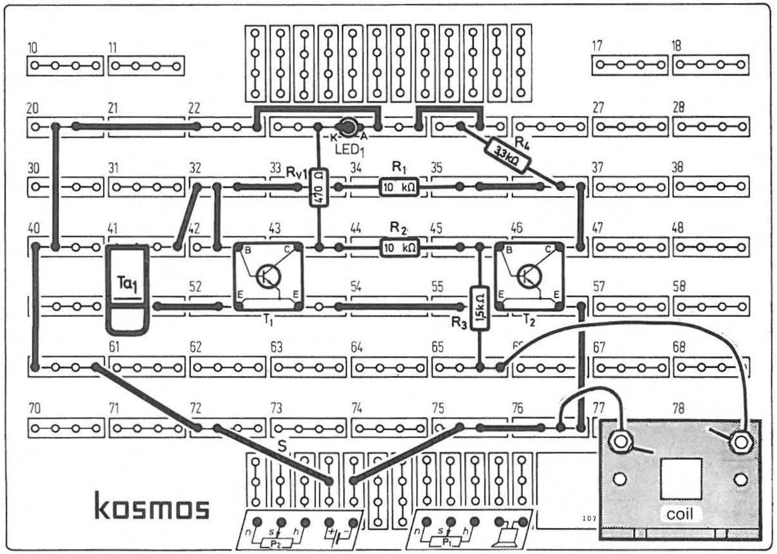

10
11
17
18
20
21
22
27
28
K
A
LED1
R4
33kΩ
30
31
32
33
Rv1
470 Ω
34
R1
10 kΩ
35
37
38
40
41
42
43
44
R2
10 kΩ
45
46
47
48
B
C
Ta1
52
54
55
57
58
E
T1
R3
1,5kΩ
T2
61
62
63
64
65
67
68
70
71
72
73
74
75
76
77
78
S
kosmos
P2
P1
coil
107

Fig. 107 Construction of circuit 108

11.18 Sensor circuits with storage

Electronic circuits, whose action is triggered by touch, are known as sensor circuits. In most cases their action depends on the fact that when they are touched a tiny current flows through the finger and this is sufficient to trigger the circuit functions. You have already met the Darlington circuit in Section 10.5 as a highly sensitive detector of the smallest current flow. You will recognize it again at the left-hand side of circuit 110, while, on the right-hand side, the amplifier module is being misemployed and adapted as a reversing switch. We will return to such applications of the amplifier module in Section 13.10. If contact clips x and y in the layout in Fig. 109 are lightly touched with the finger, then the LED lights up and remains illuminated. It can only be extinguished by pressing the “out“ contact maker.

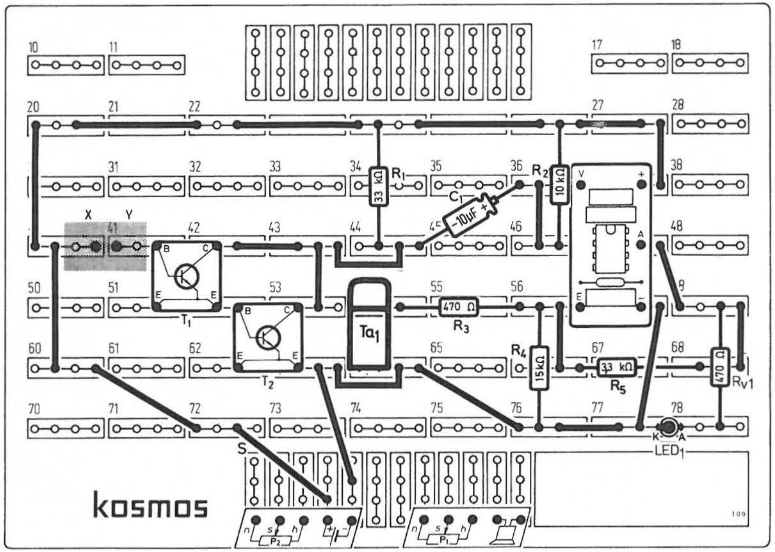

X
Y
R1
33 kΩ
R2
10 kΩ
C1
10µF
Ta1
470 Ω
R3
R4
15kΩ
33 kΩ
R5
470 Ω
Rv1
T1
T2
S
LED1
K
A
P2
P1
kosmos
109

Fig. 109 Construction of circuit 110

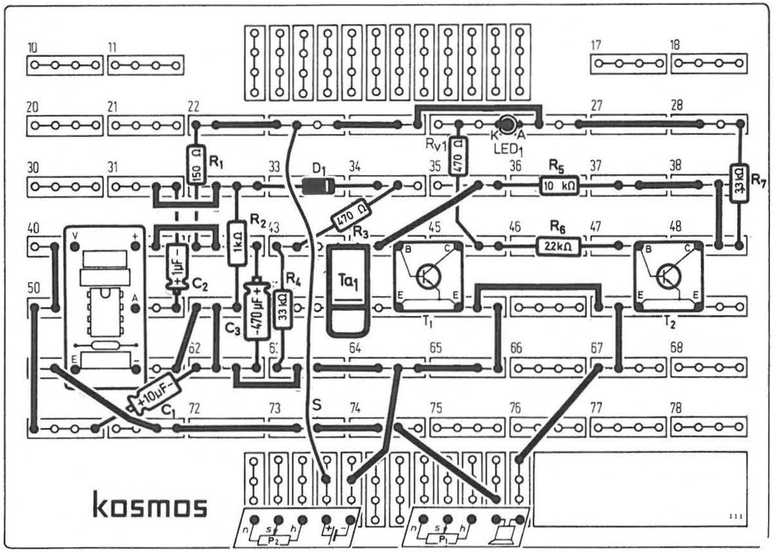

R1
150 Ω
Rv1
470 Ω
LED1
K
A
D1
R5
10 kΩ
R7
33kΩ
R2
1kΩ
470 Ω
R3
R6
22kΩ
C2
1µF
C3
470 µF
R4
33 kΩ
Ta1
T1
T2
C1
10µF
S
P2
P1
kosmos
111

Fig. 111 Construction of circuit 112

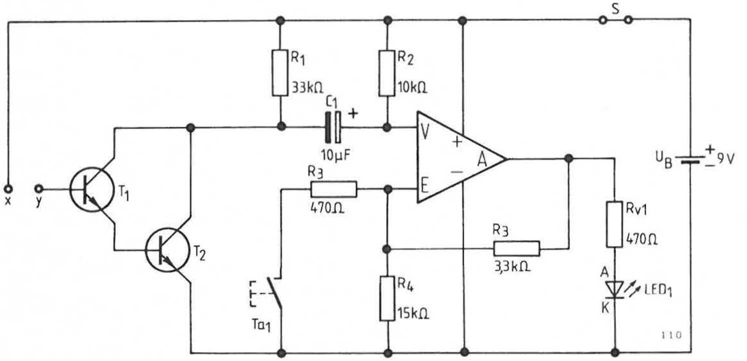

S
R1
33kΩ
R2
10kΩ
C1
+
10µF
V
+
−
A
E
R3
470Ω
R3
3,3kΩ
R4
15kΩ
Rv1
470Ω
A
K
LED1
UB
+
9V
T1
T2
x
y
Ta1
110

Fig. 110 Sensor switch with storage

11.19 Noise switch

From baby alarm to acoustic burglar alarm there is no limit to the uses to which "an electronic circuit with ears" can be put.
Here the loudspeaker is employed as the acoustic sensor, i.e. as the microphone; a loudspeaker normally converts electrical signals into mechanical vibrations, into noise. But it can also do the opposite and convert noise into an electrical potential. If it receives a sound (clap your hands in front of the loudspeaker) then it produ-

Experiment suggestion:
Potentiometer P1 can be included in the circuit so that its sensitivity can be adjusted to make sure that the room lights are not switched on by the banging of a door.

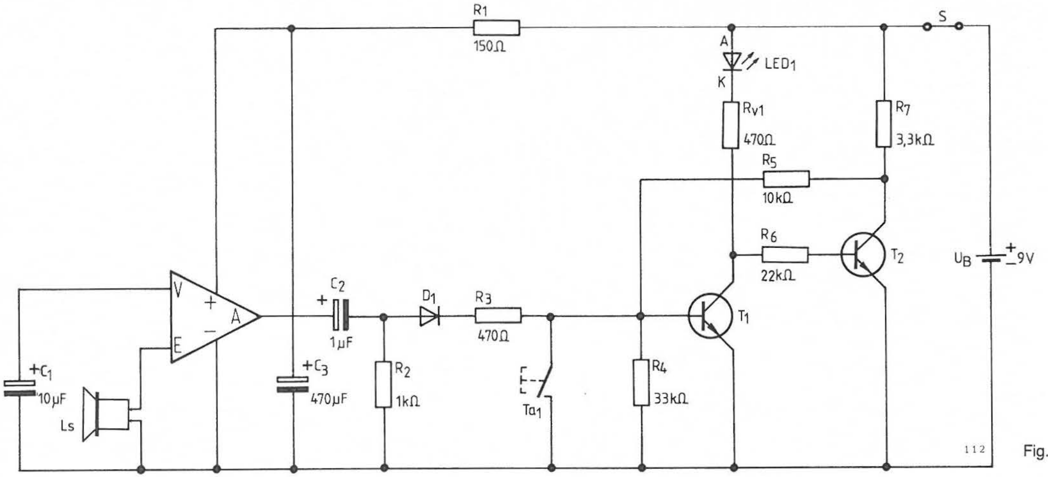


Fig. 112 A simple clap switch

ces a tiny potential, which is enormously amplified by the amplifier module (circuit diagram 112) and transmitted to the flip-flop via a diode. A single positive voltage peak at the base of T1 suffices to switch over the flip-flop. The LED lights up. It is only possible to "extinguish“ the alarm signal at the device itself by pressing the contact maker (construction diagram 111).
Experiment suggestion:
Potentiometer P1 can be built into the circuit, so that the sensitivity can be continuously changed.

11.20 On and off by clapping

Machines that obey men's voices are a modern dream and today's technologists are feverishly working on the computer programs of tomorrow, which will be able to analyze the spoken word and identify it. Here is a tiny foretaste of what technology might make possible towards the end of the century. You walk into a darkened rom, clap your hands and the room lighting is turned on as if by a hidden hand. As you leave the room you clap again and the light goes out – pie in the sky?
No, not at all. Look at circuit diagram 114; the familiar microphone amplifier to the left, to the right the electronic change-over switch (flip-flop) from Section 11.5. Instead of the LED with its protective resistor the KOSMOS switch relay X (see end of this book) can be inserted in the circuit; television, table lamp, radio, coffee machine etc. can all then be switched on and off again by a noise (clapping, whistling, calling). The clap circuit is constructed as in Fig. 113.

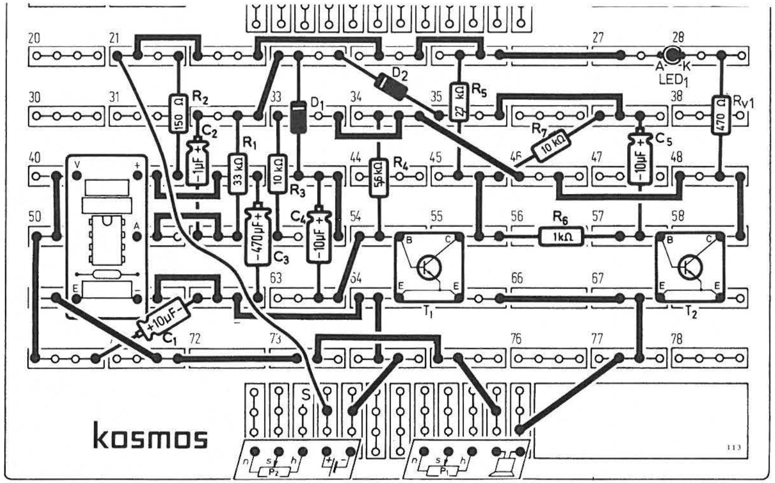
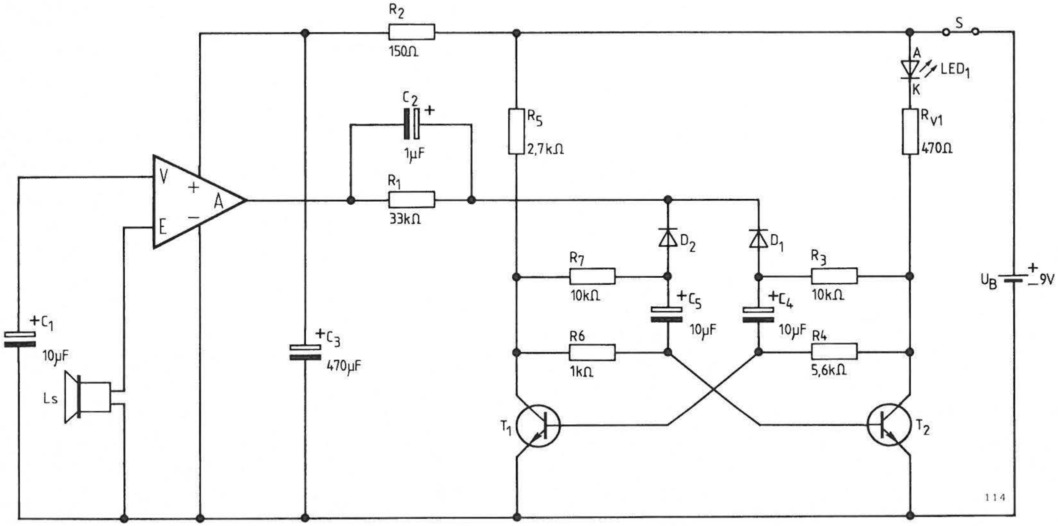

kosmos
R2
150 Ω
C2
1µF
R1
33 kΩ
10 kΩ
R3
D1
D2
R5
27 kΩ
R4
56 kΩ
R7
10 kΩ
C5
10µF
C4
10µF
C3
470µF
C1
10µF
R6
1kΩ
T1
T2
LED1
Rv1
470 Ω
P2
P1
113

Fig. 113 Construction of circuit 114

Fig. 114 Switching on and off by clapping


R2
150Ω
C2
1µF
R1
33kΩ
R5
2,7kΩ
R7
10kΩ
R6
1kΩ
C5
10µF
D2
D1
C4
10µF
R3
10kΩ
R4
5,6kΩ
LED1
Rv1
470Ω
S
UB
+9V
T1
T2
C1
10µF
Ls
C3
470µF
V
E
A
114

12. Radio technology

12.1 Alternating potential - makes electrons quiver

A potential that changes its polarity at regular intervals is known as an alternating potential. If the connections of a battery were continually exchanged then an alternating current would flow in the attached circuit. An alternating potential continually alters its polarity, alternating current continually alters its direction. There is no continuous migration of electrons in one direction, rather they move backwards and forwards in the conductor about a resting position. You have already made the acquaintance of alternating potentials and currents in your experiments, without realizing it.

The loudspeaker of the tone generator in Section 3.2, for example, was fed with alternating potential via capacitor *C2*; while the potential continually alternated (oscillated) between 0V (negative pole of the battery) and ca. +9V, capacitor *C2* continually charged and discharged. This caused electrons to flow continuously backwards and forwards between the negative pole of the battery, the loudspeaker and the plate of the capacitor. The process occurring at the output of the amplifiers can be very well represented by means of a plot of potential against time. Figure 115 shows the behavior at the amplifier output; a potential of 0V is regularly exchanged for a potential of +9V.

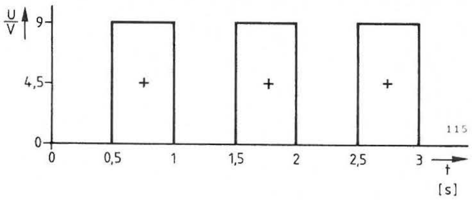


Fig. 115 Square wave d.c. voltage

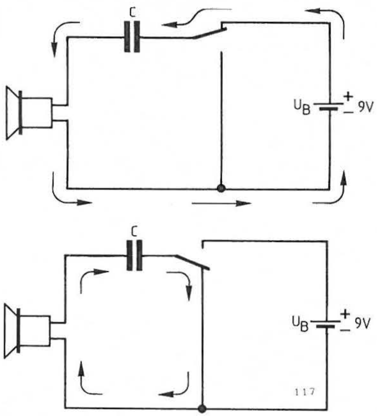


Fig. 117 Switching to produce alternating current (conventional current direction)

In Fig. 116, on the other hand, you can see that negative potentials also occur at the loudspeaker – caused by the electrons flowing back. Because of the change in potential this type of potential course is known as alternating potential. Figure 117 illustrates very clearly how a real alternating potential with positive and negative potentials can be generated from a continuously interrupted steady voltage; when the circuit is in the upper state the capacitor is charged (current flow from right to left). When the circuit is in the lower state, on the other hand, the capacitor discharges via the loudspeaker (current flow from left to right). Certain specialist terms are required for the description of the plots, these will be explained now.

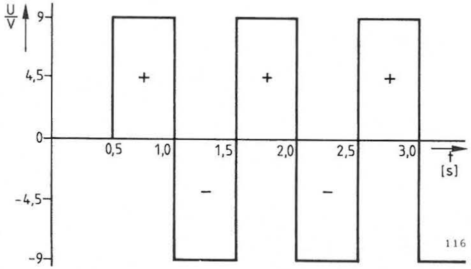


Fig. 116 Square wave a.c. voltage

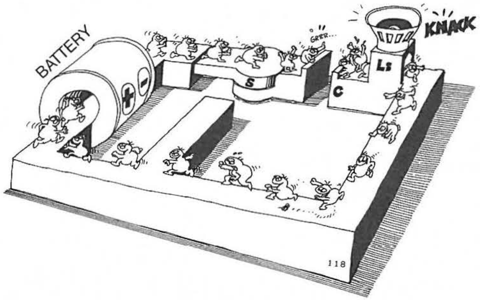


Fig. 118 Switch in the horizontal position; current flows in one direction out of the battery.

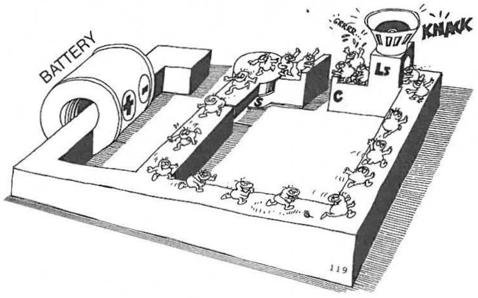


Fig. 119 Switch in the vertical position; current flows out of the capacitor in the other direction (real current direction).

The distance of a point on a plotted curve from the time axis is known as its **amplitude**. Amplitudes can be negative or positive.
Plots that repeat themselves after a certain time *T* are described as being periodic. Time *T* is known as the **period** and its reciprocal is termed the **frequency** *f*.

(F15) $f = \frac{1}{T}$

If *T* is measured in seconds then the frequency is given in Hertz (Hz).

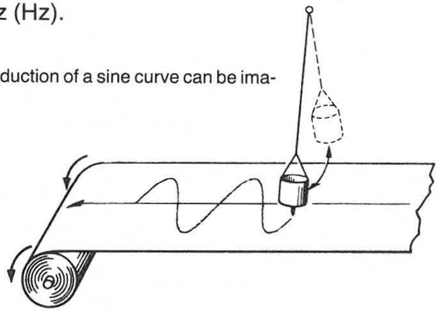


Fig. 120 The production of a sine curve can be imagined like this.

If the period *T* in Fig. 116 is 1 second, then the frequency $f = 1\text{Hz}$. The sine curve occupies a special place amongst periodic curves. Figure 120 illustrates how it is possible to visualize the generation of a sine curve.
Sine curves are technically the most important types. Generators that supply the electricity grid, for instance, produce sine-shaped potential curves. The alternating current obtained from the wall socket is supplied at a potential of 110V and a frequency of 60Hz.

12.2 From oscillations to waves

At higher frequencies it is usual to speak of oscillations rather than alternating current; these are divided roughly according to frequency into **low frequency** (AF; audio range from ca. 16Hz to 16kHz) and **high frequency** (RF; radio frequency from ca. 250kHz to 110MHz).
An oscillation that not only changes with time but also in space, that propagates, is known as a wave. Water waves and sound waves are known to you all.
When you throw a stone into water, circular water waves, which spread themselves out, are created at the point of impact. They spread at a speed of about 2m per second. When they reach the pot with the flag (Fig. 121) it is shaken up and down with the frequency of the spreading water waves. If, for instance, the waves have a frequency of four oscillations per second, then the distance between the waves will be 0.5m. This distance is known as the **wavelength**. It is calculated by dividing the speed of propagation by the frequency.

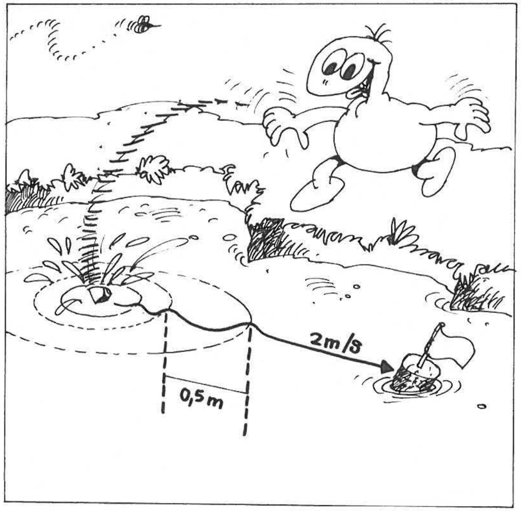


Fig. 121 The concept of wavelength

While water and sound waves require a medium (liquid, gas or solid) for their propagation, what are known as electromagnetic waves (these include light, radio and X-ray waves) can also be propagated through a vacuum (of course, otherwise how would radio contact have been kept up between the moon and the earth during the expedition to the moon on 20th July 1969? – and the same applies to the satellite communications technology that is taken for granted nowadays!).

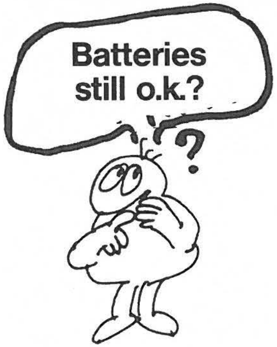
Electromagnetic waves are propagated at the speed of light, that is at the unimaginable speed of 300 000km/s. Their wavelength can be calculated from formular F16 where **y** is the symbol for wave length (greek lower case lambda).

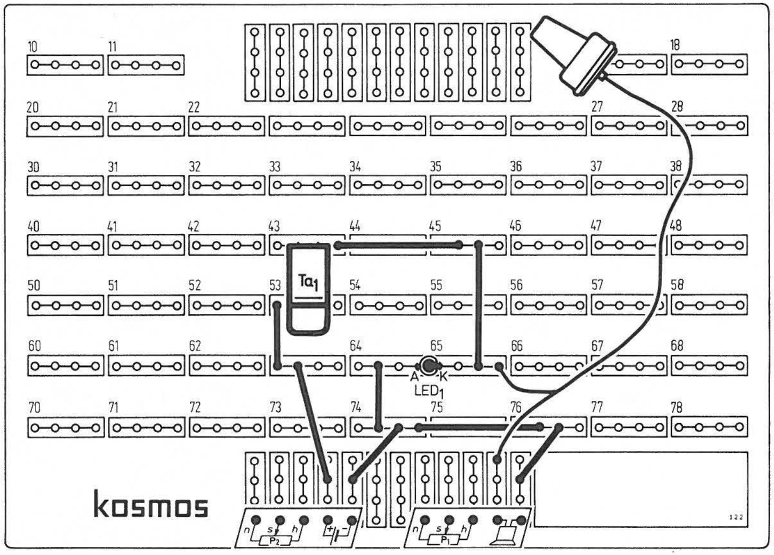
F16
$$\lambda\ (m) = \frac{300\,000\ (km/s)}{f\ (kHz)}$$

The Stuttgart radio transmitter has a frequency of 576kHz, that is a wavelength of 520.83 meters.
Before we discuss the transmission and reception of radio waves we need to take a look at the properties of coils, which are always amongst the components of radio receivers.

12.3 Self induction

You are sure to remember from your physics lessons that every coil with a current flowing through it produces a magnetic field ("electromagnetism"). But perhaps you do not recall as clearly the fact that when the current in the coil is switched off a potential is induced, which tries to maintain the current in the coil until the energy of the magnetic field is exhausted. This is known as "self induction". A coil that produces a potential of 1V when the current changes by 1A per second possesses a self induction (*L*) of 1 henry (H). This relationship means, that the self-induced potential does not just depend on the self induction *L* of a coil (the larger the number of windings the larger the self induction) but also on the rate of change of the current. The unit of measurement, henry, is named after the American physicist Joseph Henry (1797 - 1878), who discovered self induction in 1834.


Batteries still o.k.?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43
44
45
46
47
48
50
51
52
53
Ta1
54
55
56
57
58
60
61
62
64
65
A
K
LED1
66
67
68
70
71
72
73
74
75
76
77
78
kosmos
P2
P1
122

Fig. 122 Construction of circuit 123

12.4 Energy transformation

In layout 122 you are employing the loudspeaker and earphone as two series connected coils in order to demonstrate their self induction (circuit diagram 123).

Press the contact maker several times quickly and observe the LED: It lights up quickly for an instant each time the contact maker is released. This can be best observed, when the contact maker is released as quickly as possible, for example, press it with your finger nail and then move your nail rapidly sideways so that the contact maker flips upwards (carry out the experiment in a darkened room – some LEDs only illuminate very, very weakly!).

Two things can be observed:

1. The more rapidly the current changes (in this case by switching off) the greater is the induced potential (brightness of the LED).

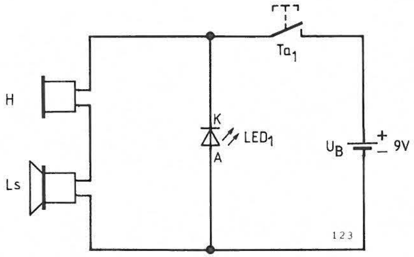

Ta1
H
Ls
K
A
LED1
UB
+
–
9V
123

Fig. 123 Induction experiment

2. The induced potential opposes the battery potential (the LED is wired in the nonconducting direction for the battery).

12.5 Oscillation between two states

In the last section you observed that a current flowing through a coil creates a magnetic field. The magnetic energy stored in this field is transformed back into electrical energy at the instant that the circuit is broken, thus causing the LED to blink on. If this electrical energy is led to a capacitor, this charges itself and thus stores the electrical energy. As soon as the charging process is complete, the capacitor begins to discharge again via the coil. The discharge current once again creates a magnetic field around the coil and the electrical energy is transformed once more into magnetic energy.

The energy thus oscillates backwards and forwards between two states, it is alternately transformed into electrical and magnetic energy. A circuit that makes this to-ing and fro-ing possible is known as an **oscillator circuit**. Figure 124 illustrates the basic circuit diagram of a parallel oscillator circuit consisting of *L* and *C*. A current which maintains the magnetic field flows through the coil all the while the contact maker is pressed. As soon as the contact maker is released the energy between *L* and *C* begins to travel to and fro.

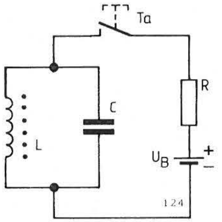


Fig. 124 A basic oscillator circuit

The swinging back and forth is the slower the larger the capacity of the capacitor and the inductance of the coil. The frequency of the oscillations can be calculated in Hz from the Thomson oscillator formula F17 by inserting *C* in farad and *L* in henry. The formula is named in honor of the British physicist William Thomson (1824-1907, from 1892 Lord Kelvin).

F17
$$f = \frac{1}{2 \pi \sqrt{L \cdot C}}$$

In theory these oscillations ought to continue forever. However, thermal losses occur because the windings of the coil offer a resistance to the flow of current, so that the oscillations slowly decay. Hence, the size (amplitude) of the oscillations gets smaller from oscillation to oscillation (Fig. 125). Such a train of oscillations is known **damped oscillations** and the process is known as attenuation.

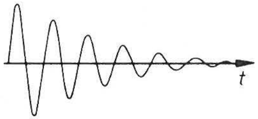


Fig. 125 Damped oscillations

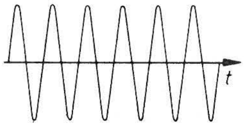


Fig. 126 Undamped oscillations

Figure 126 shows **undamped oscillations** which are sine-shaped and which take place when the losses (apart from the thermal losses in the coil these include dispersion losses of the magnetic field and dielectric losses on discharge of the capacitor) are compensated for at every oscillation. The negative halves of the waves are caused by the fact that the magnetic field flows in the opposite direction, when the current flows back out of the capacitor and the capacitor is then recharged in the opposite direction.

12.6 A cow drinks its own milk

Figure 128 illustrates a circuit which sets up undamped oscillations in a loop of the circuit, it is known as an **oscillator circuit** . In it T1 whose collector lead forms part of the oscillating loop is “base connected“ (the base receives constant unchanging potential, emitter = input and collector = output of the transistor). The coil of the earphone is again employed as the inductance. Since the earphone possesses a resistance of 600Ω, Fig. 128 shows a “substitute“ for the earphone in the form of an inductance in series with a resistance. The oscillation is initiated by the current impulse on switching on. A portion of the alternating potential is led to the transistor “input“ (that is the emitter in the case of base connection), which is therefore maintained in time with the oscillations. The transistor now amplifies the incoming oscillations and, thus, maintains the oscillations in the loop by means of its output. It is possible to compare the transistor with a cow (Fig. 129), which consumes a portion (the oscillations tapped of from the output) of the milk it produces (amplified oscillations).

This oscillator circuit is known as a capacitive autodyne circuit or, in honor of its inventor, as a Colpitts oscillator (construction according to Fig. 127). It oscillates with a frequency that can be calculated from formula F17. In our case it is ca. 2kHz. The frequency at which an undamped oscillator circuit oscillates is known as its **resonance frequency**.

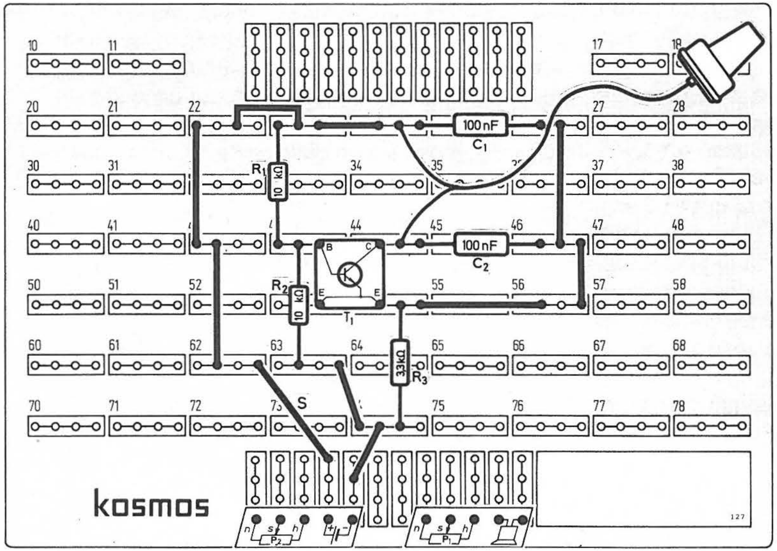

100 nF
C1
R1
10 kΩ
100 nF
C2
R2
10 kΩ
B
C
E
T1
33 kΩ
R3
S
kosmos
127

Fig. 127 Construction of circuit 128

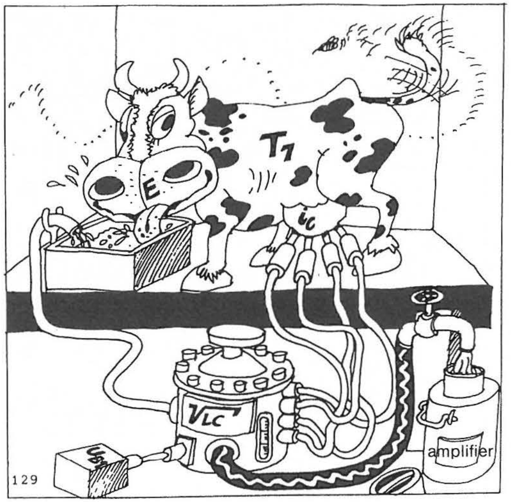

T1
E
ic
VLC
UB
amplifier
129

Fig. 129 Positive feedback; the cow consumes a portion of its own milk.

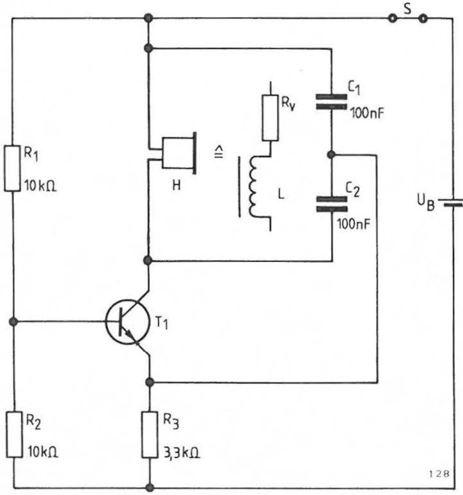
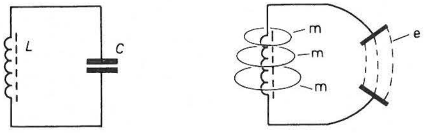

S
C1
100nF
Rv
R1
10kΩ
H
≙
L
C2
100nF
UB
+
9V
T1
R2
10kΩ
R3
3,3kΩ
128

Fig. 128 Note generator with oscillator circuit

12.7 Between transmitter and receiver

Now let us return to radio reception. The interesting question here, of course, is how does the radio signal cross the space between the transmitter and the receiver? You already know that a coil with a current flowing through it is surrounded by a magnetic field and that a charged capacitor has an electrical field between its two plates. Both fields pass through space, but neither of them exerts an effect at a distance when the oscillator circuit is complete. The electrical field cannot escape from between the thickly packed capacitor layers and the magnetic field that surrounds a closed circuit only expands a little way in spacially a few times the diameter of the circuit.

This changes if we open the oscillator circuit: Fig. 130 shows that the lines of electrical force (e)



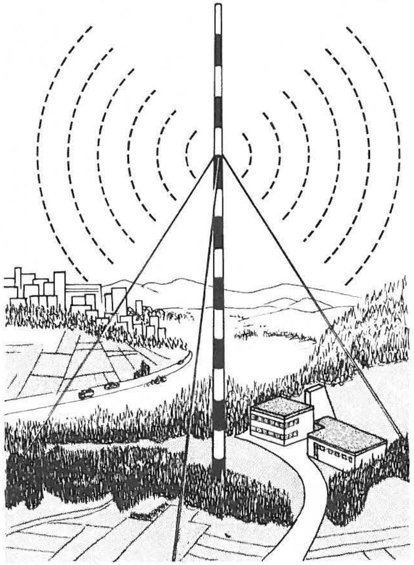


Fig. 131 A self-oscillating transmitter mast

become longer if you open up the capacitor. In an open oscillator circuit the capacitor charge is built up between the aerial wire and the earth. Here the lines of magnetic force (m) can propagate themselves like the circular waves from a stone dropped into water. The electrical waves follow the magnetic ones, so that the whole field detaches from the aerial and migrates through space in the direction of the arrow (b). Modern transmitting aerials are no longer horizontal wires but self-oscillating masts ¼ of a wavelength high (Fig. 131).

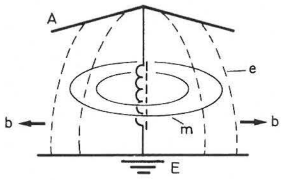


Fig. 130 Open oscillator circuit

12.8 Aerial and earth

At the receiver the electrical field forces of the radio waves act on the aerial you have set up and cause the electrons in it to vibrate backards and forwards. Set up a 6 m long wire on the wall as near the ceiling as possible, connect a second wire as earth to a bright metal portion of the heating system or to a water faucet. If the aerial and earth are now connected by an oscillator circuit and if, in addition, the frequency of the radio waves that are being received is the same as the resonance frequency of the circuit, then this is stimulated to continual, that is undamped, oscillation. In order to adjust the resonance frequency precisely to that of the incoming radio waves wire connectors can be inserted that connect additional capacitors in parallel to the oscillator circuit and the iron core in the coil can be turned (alteration of the inductance). This is nothing more or less than "tuning the radio to a transmitter".

12.9 You build an AM radio

The heart of our receiver is the oscillator circuit on the AM (amplitude modulation) module (Fig. 132), which consists of a coil (or more precisely a "double coil") with iron core and various capacitors. The choice of transmitter is first made roughly by bringing capacitors into the circuit (individually or in parallel) by means of connecting wires on the plug board.

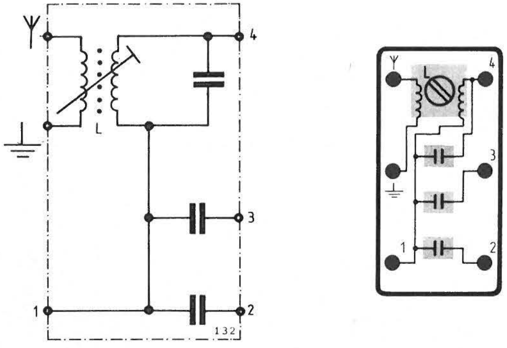


Fig. 132 The KOSMOS AM module

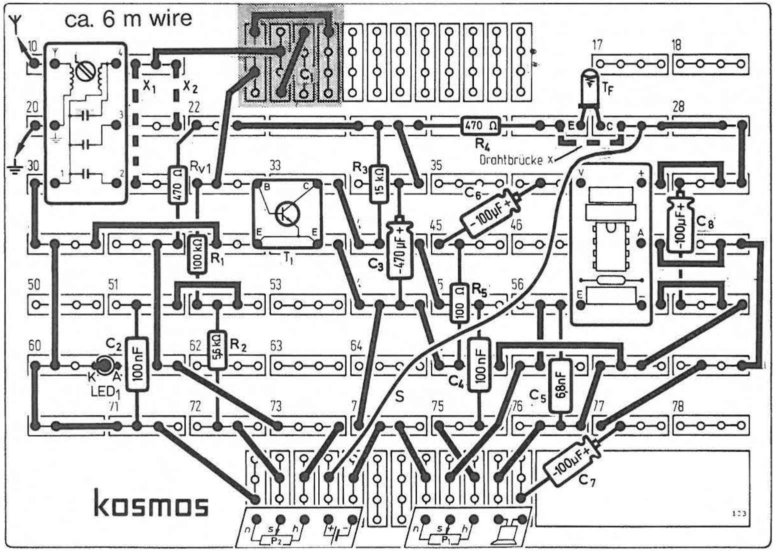
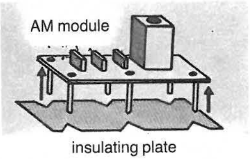

ca. 6 m wire
10
20
30
X1
X2
22
Rv1
470 Ω
33
B
C
E
T1
R3
15 kΩ
35
C6
-100µF+
45
46
C3
-470µF+
R1
100 kΩ
17
18
TF
28
E
C
470 Ω
R4
Drahtbrücke x
V
A
E
-100µF+
C8
50
51
53
5
R5
100 Ω
56
60
C2
100nF
62
5,6kΩ
R2
63
64
K
A
LED1
71
72
73
S
75
C4
100nF
76
C5
68nF
77
78
-100µF+
C7
kosmos
P2
P1
n
s
h
133

Fig. 133 Construction of circuit 134


AM module
insulating plate

The fine tuning can then be performed, if necessary, by turning the iron core (with a small screwdriver). But take care – never use force otherwise the core could be damaged; only two turns are possible backwards and forwards.

A word first about the “double coil“ we mentioned, before you construct the receiver according to Fig. 133. It has been found to be very useful, particularly when there are two or more equally strong transmitters, not to couple the aerial and earth directly in an oscillator circuit but to have them electrically separated but, nevertheless, connected to it via the iron core and the second coil as in a transformer (better resolution).

And another comment:

For this radio circuit place the wire connector x between contact clips 26 and 27 in construction diagram 133. The phototransistor Tf is not required until Section 14.20.

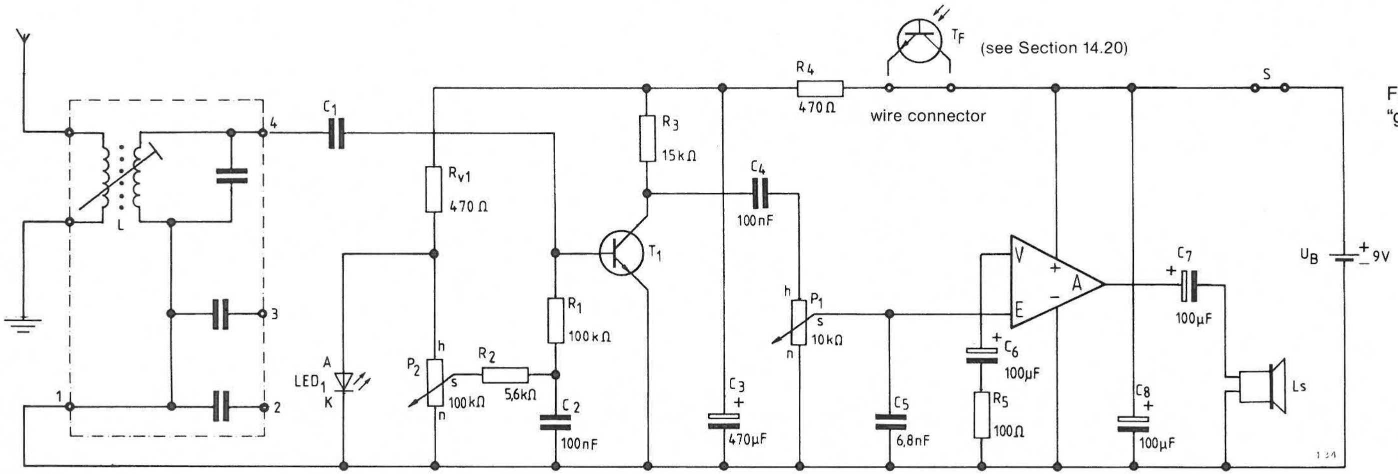

TF
(see Section 14.20)
R4
470 Ω
wire connector
S
C1
4
L
3
2
1
Rv1
470 Ω
R3
15 kΩ
C4
100 nF
T1
R1
100 kΩ
LED1
A
K
P2
h
s
n
100 kΩ
R2
5,6kΩ
C2
100 nF
C3
470µF
h
P1
s
10kΩ
n
C5
6,8nF
V
E
A
C6
100µF
R5
100Ω
C7
100µF
C8
100µF
UB
9V
Ls
134

Fig. 134 AM radio on the “grid leak“ principle

Bringing the AM radio into service.
Check the construction very carefully and switch on the current (insert the long wire S). Connect the earth and aerial. Turn the loudspeaker control P_1 to the right. Gently turn P_2 until you hear a faint noise. Now tune to the transmitter as described above: Use wire connectors x_1 and/or x_2 to connect the various capacitors of the module, perform any necessary fine tuning by rotating the iron core.

12.10 Modulation and demodulation

If you find it difficult to accept that we are constantly surrounded by electromagnetic waves – without being able to see, smell or hear them – then it will seem almost miraculous that these waves also transport information (e.g. speech and music, which also take the form of oscillations) through the ether.
However, it is not so difficult to understand if you consider the following argument.
Let us assume that the transmitter is at the moment "not on the air", the RF (radio frequency) oscillations are still being transmitted but no speech or music is being broadcast. The transmitter is then said to be only broadcasting its **carrier wave**. When radio stations give information concerning their broadcasting frequency then they are always referring to the frequency of their carrier wave.
This strange name is employed because – when the broadcasting pause has ended and the broadcaster begins to speak – this wave "carries" the information "piggyback", as it were, to the receiver. The process by which a carrier wave carries additional information on its journey is described as *modulation*. Modulation means that the carrier wave is changed slightly, in such a way that it exactly mirrors the changes in the pitch and loudness of the information (speech, music, noise). There are basically two forms of modulation employed in radio transmission: **Amplitude** and **frequency** modulation.

12.11 Amplitude modulation (AM)

The principle is very simple: The amplitude of the carrier wave is slightly altered in time with the audio frequency (i.e. speech, music, etc.). Figure 136 shows the pure carrier wave, that does not contain any information ("not broadcasting"). All the carrier waves have the same height (amplitude).

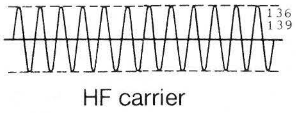


Fig. 136 Radio frequency (RF)

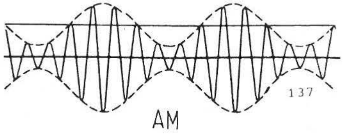


Fig. 137 Amplitude-modulated radio frequency

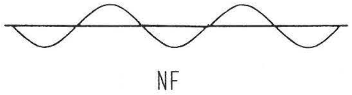


Fig. 135 Audio frequency (AF) oscillations

Things look different in Fig. 137. Here the amplitude maxima describe a wave from (both the upper and lower simultaneously) and this wave form corresponds point for point with the audio frequency illustrated in Fig. 135, which is printed directly below to assist comparison. To put things very simply, it can be imagined that the reception strength of the radio receiver changes very, very slightly with the rhythm of the audio frequency – for the magnitude of the amplitude is equivalant to the reception strength. The task of the radio receiver is now to filter out these slight differences from the carrier wave, a process that is known as *demodulaton*. The signal that is filtered out in this way can then be amplified and fed to the loudspeaker.
Amplitude modulation is employed for long, medium and short wave transmissions. Unfortunately amplitude-modulated waves have a distinct disadvantage for the radio listener; they are very susceptible to interference. You can

experience this for yourself by listening to an AM receiver near a streetcar line or during a thunderstorm. The reception strength, i.e. the amplitude of the carrier wave, is changed so much by the interference that the information it contains is often lost in the interference. But naturally there is also an advantage involved; amplitude-modulated waves have an astonishing range; they are not blocked by every irregularity in the ground and it is possible to receive them on the other side of a skyscraper.

12.12 Grid leak circuit – memories for old-timers

The circuits employed when radio technology began were of particular originality, because it was necessary to extract the best possible out of a set while using the simplest, often homemade means available – this was necessary if only because the transmitters did not have the enormous outputs available today.

One possibility of demodulating the radio frequency input and at the same time amplifying the result (that is the audio frequency component) was the grid leak circuit, which was in use for economy's sake even after the Second World War – there were naturally no transistors then, the good old radio valves were used instead and that is where the circuit go its name; the grid of a radio valve was rather similar to the base of a transistor.

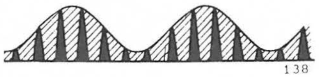


Fig. 138 Modulated, rectified RF

The circuit diagram of a transistor-based "grid leak circuit" is shown in Fig. 134. Transistor T1 has a double function; its base-emitter diode slices away the bottom half of the radio frequency oscillation, which is fed to it via *C*1 (rectification see Fig. 138); because of their relatively long time constants *R*1 and *C*2 ensure that the radio frequency of the remaining upper portion is suppressed, so that a current flows through *R*1 with the rhythm of the modulation, that is the audio frequency. This completes the demodulation and the second function of the transistor comes into play: The varying current through *R*1 causes a variation in the base current and this is amplified – as is normal in a transistor – and appears at the collector.

This "grid leak" principle is certainly a fascinating idea; unfortunately – as is often the case in real life – there are also disadvantages. In order to avoid the inhibitory effect of the threshold potential of the base-emitter diode, the working range of the transistor has to be so finely adjusted with the potentiometer P2, that even the smallest potentials, in this case the extremely weak radio frequency potential, can be rectified.

The purpose of the LED is merely to limit the range of adjustment of the potentiometer to 1.6V; this makes it much easier to find the correct working range.

Another peculiarity must also be pointed out. We are simply employing two adjacent contact clips as the coupling capacitor *C*1; they are colored light grey in the construction diagram 133. You can see that twice two contact clips "in parallel" makes up capacitor *C*1 – a trick that is reminiscent of the good old pioneer days of "steam radio".

12.13 Frequency modulation (FM)

This is mainly employed in the VHF range (radios nowadays usually have the scale labelled FM = frequency modulation, an abbreviation which is internationally employed, rather than VHF = very high frequency). In this type of modulation it is the carrier frequency itself and not its amplitude that is modulated in the rhythm of the AF signal. If, for example, an VHF transmitter of 100 MHz is re-

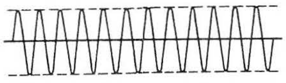


Fig. 139 Radio frequency (RF) oscillation

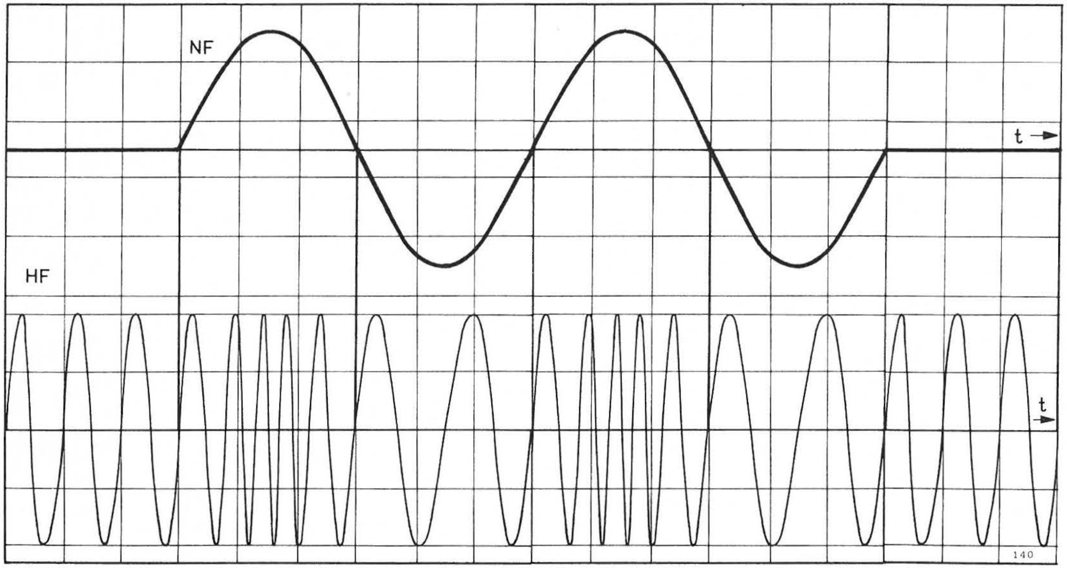
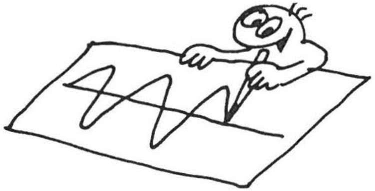


Fig. 140 Frequency-modulated radio frequency

ceived, then the actual frequency received can vary between 99.910 MHz and 100.090 MHz depending on the amplitude of the AF signal (that is the volume level). These relationships are illustrated in Figs. 139 and 140. Figure 139 illustrates the unmodulated carrier wave, in Fig. 140, on the other hand, it can clearly be seen that the frequency varies, while, as already mentioned, the amplitude does not alter in this form of modulation.

The receiver has to filter out (demodulate) the information contained in the frequency variations, amplify it and feed it to the loudspeaker. Frequency-modulated waves are considerably more resistant to interference because effects on the RF amplitude do not make themselves felt. The information is carried in the transmission frequency. However VHF waves only have a very limited range and a normal house of brick or stone can be an impenetrable obstacle since the waves propagate themselves in a straight line.



12.14 Building a FM receiver

One method of retrieving the information (speech and music) buried in the changing frequency is what is known as **flank demodulation**. This makes use of the fact that – to put it in an oversimplified manner – the resistance of an oscillator circuit changes depending on the frequency applied to it. Thus, variations in frequency result in changes in resistance and these resistance changes can then be transformed into current or voltage variations, amplified and fed into the loudspeaker to make them audible.

The oscillator circuit of the FM receiver that you are going to build contains, apart from a coil, a *capacitance diode* Dk which is a modern substitute for a variable capacitor. Such a diode has a great advantages and that is that its capacitance can be "adjusted" by the application of a dc voltage. This adjustment voltage is taken in Fig. 143 from the slide of potentiometer P2 so that this potentiometer can be employed for tuning to the transmitter.

12.15 Self-quenching to order

The construction of the FM receiver requires a very compact arrangement of the components, since even the capacitance of the connecting wires has an effect on the circuit and could, under certain conditions, cause it to fail; for this reason the most important components – coil, capacitance diode and transistor (this is of a type known as a **field-effect transistor** which is particularly suitable for use at high frequencies) and capacitors – are combined into a receiver module. The whole "radio" is, therefore, mounted on the little board and we must not expect wonders from this tiny receiver component, but rather enjoy experimenting with it to tease it into life.

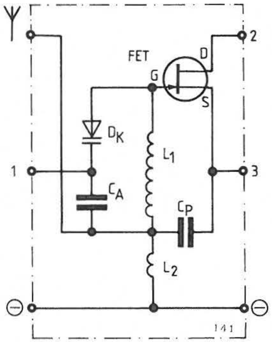
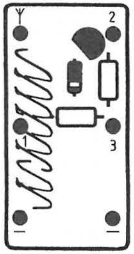
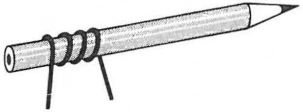

FET
D
G
S
2
1
3
D_K
L_1
C_A
C_P
L_2
⊖
⊖
141

Fig. 141 The KOSMOS FM module

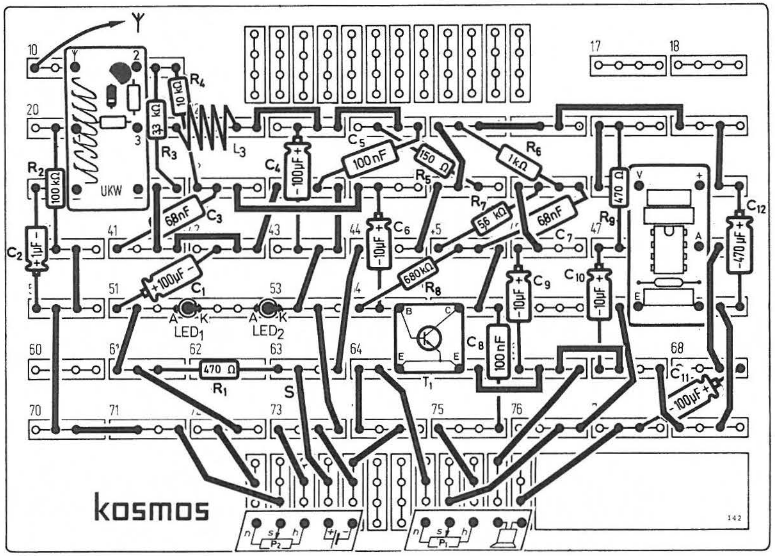




wind coil L3 from a 15 cm length of wire.

The circuit works according to what is known as the **self-quenching process** – a method that could not be simpler and that also possesses a very high sensitivity but which, nonetheless, has fallen into disuse for industrial purposes with their great demand for ease of operation and reception quality. Nevertheless we will briefly discuss this principle of reception which rejoices in the name of super-regenerative reception. You already know that an externally stimulated oscillation fades in an oscillator circuit if new energy is not continually fed into it – for instance in the case of the Colpitts oscillator in Section 12.6 the transistor ensured a continuing provision of energy by means of a **feedback system** and hence ensured undamped oscillations. The smaller the losses of an oscillator circuit are (or to put it in another way the less the circuit is damped) the less energy must be provided, in order to maintain the oscillations. As far as the losses of the components are concerned there is a lower limit which is determined by the cost of the components. The super-regenerative receiver therefore employs a trick: The attenuation of the oscillator is stopped by switching the feedback rapidly on and off. Just before the feedback is applied there is a virtually complete lack of damping and the reception conditions for incoming radio waves are almost perfect. Now if it is arranged that the frequency of switching the feedback on and off is above the audible range, so that the listening pleasure is not affected, this dedamping trick produces an extraordinarily sensitive receiver, which can be employed without an aerial if the reception is good.

Fig. 142 Construction of circuit 143


10
20
17
18
UKW
R_4
10 kΩ
33 kΩ
R_3
L_3
R_2
100 kΩ
C_2
1µF
C_4
100µF
C_5
100nF
150 Ω
R_5
1kΩ
R_6
R_7
56 kΩ
68nF
C_7
470 Ω
R_9
C_{12}
470 µF
68nF
C_3
41
43
44
C_6
10µF
680kΩ
R_8
C_9
10µF
C_{10}
10µF
51
53
100µF
C_1
LED$_1$
LED$_2$
60
62
63
64
470 Ω
R_1
S
B
C
E
E
T_1
C_8
100nF
68
C_{11}
100µF
70
71
73
75
76
kosmos
P_2
P_1
142

12.16 Construction of the super-regenerative FM receiver

The set is constructed as in Fig. 142 (circuit diagram 143); insert the switch connector S after making a careful check. The LEDs should now illuminate and a slight hiss should come from the loudspeaker.

Now turn the potentiometer knob very slowly until a transmitter can be heard. The fine adjustment now begins in order to achieve an optimal reception. The following measures can be tried out:

1. Depending on the strength of the signal from the transmitter, values of 2.7kΩ, 33kΩ or 100kΩ can be tried out for *R*2.
2. A piece of wire can be inserted into contact clip 10 as an aerial. The position of the wire should be adjusted by trial and error.
3. Contact clip 78 can be attached to a water faucet or to a bright metal part of the heating system by means of a piece of wire.
4. The first two turns of the coil on the FM module can be carefully separated or pressed together.
5. The whole set can be turned to and fro to find the best position for reception.
6. The reception range can be changed (to receive transmitters that are right at the end of the scale, for instance), by carefully spreading out or compressing the last 6 windings of the coil.
7. The windings of the homemade coil can be carefully separated or compressed (only in the lengthways direction).

The suggested measures can improve the reception of the set but they can also make it worse. You must find the best conditions by careful trial and error.

13. Audio frequency techniques – notes and noises

Frequencies that lie in the audible range are known as audio frequencies or AF for short. Now “audible“ is a very flexible term, for children's ears are more sensitive to high and low notes than the ears of an elderly man, bat's ears have a different sensitivity range than those of the horse. It has, therefore, been agreed that audio frequency

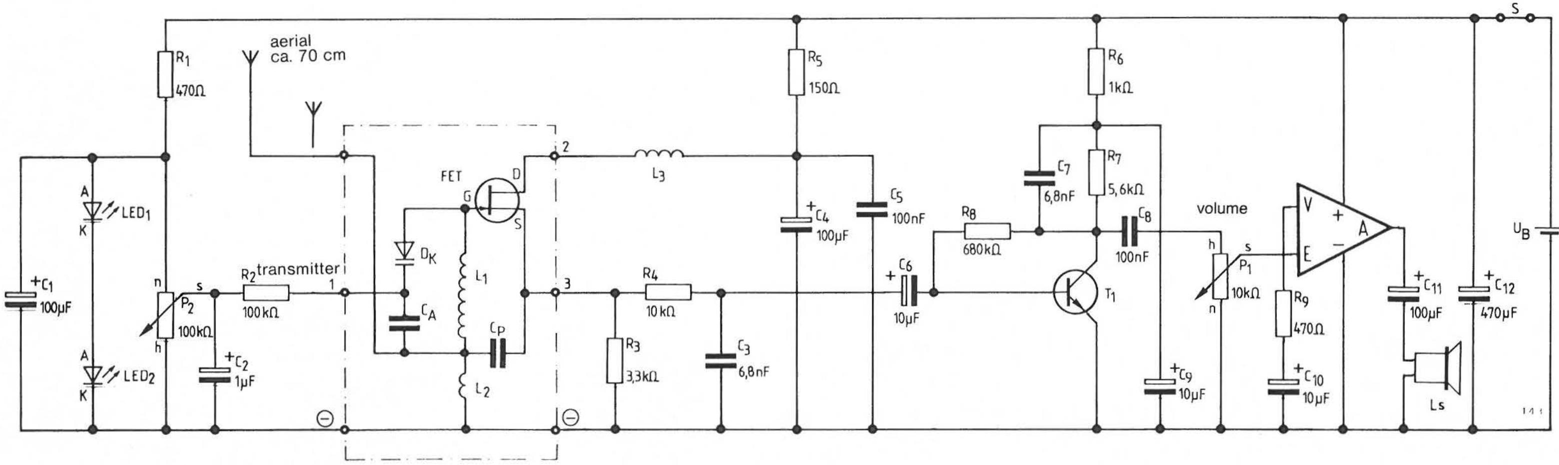


Fig. 143 FM receiver on the super-regenerative principle

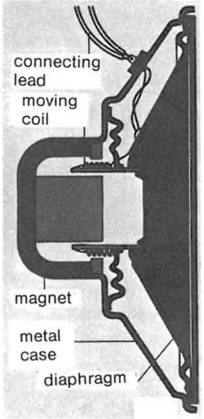
aerial
ca. 70 cm
R1
470Ω
A
K
LED1
LED2
+C1
100µF
n
s
h
P2
100kΩ
R2 transmitter
100kΩ
1
+C2
1µF
FET
G
D
S
DK
CA
L1
L2
Cp
2
3
⊖
⊖
L3
R4
10kΩ
R3
3,3kΩ
C3
6,8nF
R5
150Ω
+C4
100µF
C5
100nF
+C6
10µF
R6
1kΩ
R7
5,6kΩ
C7
6,8nF
R8
680kΩ
C8
100nF
T1
+C9
10µF
volume
h
s
n
P1
10kΩ
V
E
A
+
−
R9
470Ω
+C10
10µF
+C11
100µF
Ls
+C12
470µF
UB
+9V
S

should apply to the frequency range between 16Hz and 16kHz – in spite of the protests of some hi-fi freaks who maintain that the upper limit ought to be 20kHz or even 40kHz.

13.1 Movement produces sound

In order to enjoy hearing electronically produced or amplified music you need an acoustic electrical transducer, or more down-to-earth a loudspeaker or earphone. Figure 144 shows a section through a loudspeaker or earphone. You can see a diaphragm, a moving coil, a bowl-shaped magnet and the loudspeaker body. The coil is free to move backwards and forwards over the round internal portion of the magnet and this causes the diaphragm, which is attached to the coil, to move backwards and forwards. If a current flows through the coil it produces a magnetic field, which can either oppose or supplement the field of the loudspeaker magnet depending on the direction of the current. Accordingly the coil is either attracted inwards or repulsed outwards and the diaphragm moves appropriately. If the current in the coil oscillates (say in time to music), then the coil makes the appropriate movements and produces vibrations in the air which are experienced by our ears as a musical note.

Fig. 144 Construction of a loudspeaker


connecting lead
moving coil
magnet
metal case
diaphragm

13.2 A hearing tester (audiometer)

Why not start an experiment with your own ears. Set up a hearing tester according to Fig. 145 (circuit diagram 146), which is known to the people with higher education as an audiometer. The hearing will be tested at the high and highest notes – the tester is not suitable for low frequencies.

First turn P1 completely to the left and switch on the apparatus by inserting wire connector S. A note will now be audible which seems very high to you. Now turn the potentiometer switch slowly to the right and you will hear the pitch of the note increase, until you get the impression that you cannot hear it anymore. You can read the hearing limit off roughly from the scale: "0" corresponds to 2.5kHz, "2" to 3kHz, "4" to 4.5kHz, "5" to 10kHz, at slightly over "5" (5.3) you reach 15kHz. But these should only be taken as approximate values; because of the unavoidable variations of the components, your instrument is very far from being an officially calibrated audiometer.

Fig. 146 Audiometer

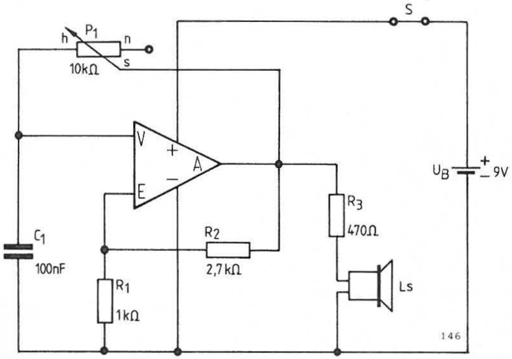
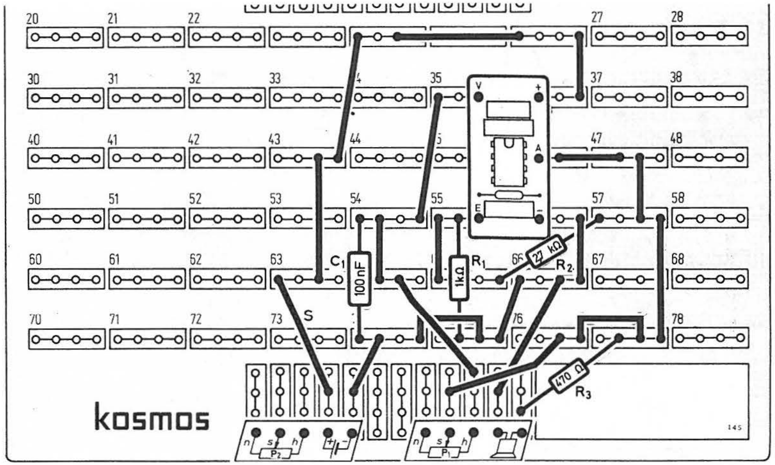

S
h
P1
n
s
10kΩ
V
+
A
−
E
C1
100nF
R1
1kΩ
R2
2,7kΩ
R3
470Ω
Ls
U_B
+
9V
146

Fig. 145 Construction of circuit 146


20
21
22
27
28
30
31
32
33
35
37
38
40
41
42
43
44
47
48
50
51
52
53
54
55
57
58
60
61
62
63
C1
100nF
1kΩ
R1
27kΩ
R2
67
68
70
71
72
73
S
76
78
V
+
A
E
470Ω
R3
kosmos
P2
P1
145

13.3 Front door and back door – an amplifier with two inputs

When you look at the block circuit diagram of the amplifier module (Fig. 147) you will be puzzled to see that it possesses two inputs, although you would think that in order to amplify a signal (speech, music, noise) you would only require one input (compared with ground). The integrated circuit of the amplifier module contains what is known as an input differential amplifier, and we are now going to discuss the properties of such differential amplifiers.

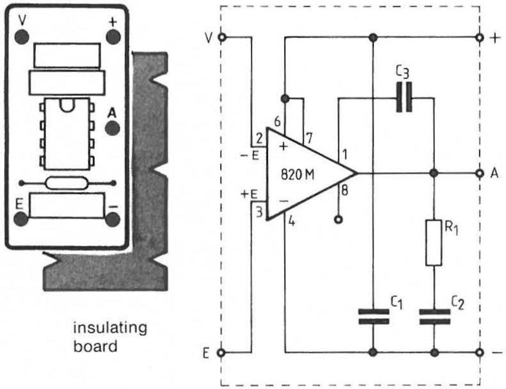
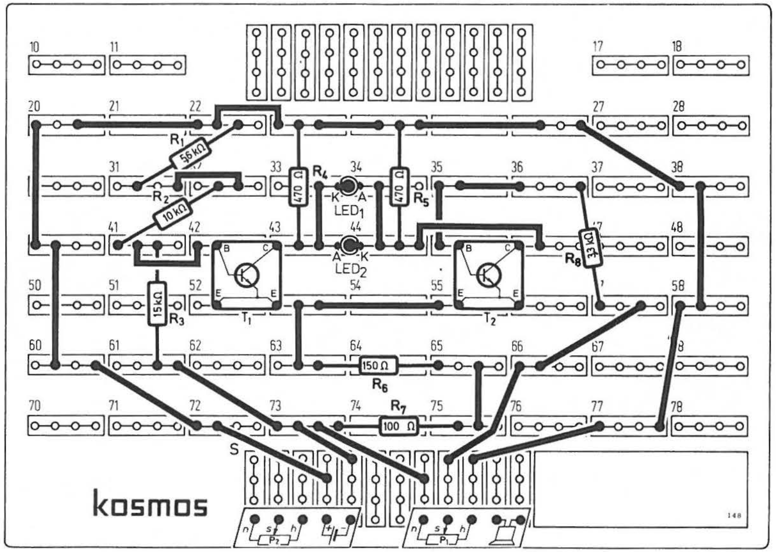

V
+
A
E
–
insulating board
V
–E
+E
E
2
3
4
6
7
1
8
820 M
C3
C1
C2
R1
+
A
–

Fig. 147 The KOSMOS amplifier module

Fig. 148 Construction of circuit 149


10
11
17
18
20
21
22
27
28
R1'
56kΩ
31
33
34
35
36
37
38
R2
10kΩ
R4
470 Ω
LED1
470 Ω
R5
41
42
43
44
47
48
B
C
E
LED2
T1
T2
R8
33kΩ
50
51
52
54
55
58
15kΩ
R3
60
61
62
63
64
65
66
67
150 Ω
R6
70
71
72
73
74
R7
100 Ω
75
76
77
78
S
kosmos
P2
P1
148

13.4 Pinching mistakes – the differential amplifier

Imagine a transistor, that is suffering from the summer heat; it reacts by lowering its base-emitter potential (2.3 mV per degree Celsius). This, in its turn, is taken amiss by the working range of the transistor; it is displaced and opens the door for distortions. But electronics is supposed to produce undistorted music, so something clever had to be thought of, and someone remembered the old physicist's trick, of letting an error occur twice and taking the difference so that the error disappears.

This is exactly what takes place in an (ideal) **differential amplifier**. Two transistors are used instead of one and it is ensured that both have the same temperature error, the difference between the input signals is taken and, low and behold, the temperature error disappears!

13.5 Smaller – bigger – equal?

Figure 149 illustrates the circuit of a differential amplifier. The left-hand input (base of the left-hand transistor) is about 4.5V via a fixed voltage divider – the right-hand input, on the other hand, is connected to the potentiometer slide and can be adjusted between 0V and +9V. If the potentiometer is adjusted to its midpoint (4.5V at the potentiometer slide), then the difference between the input voltages is equal to zero, the difference between the output voltages, which is measured by connecting two antiparallel LEDs to the collectors, is also equal to zero (both LEDs extinguis-

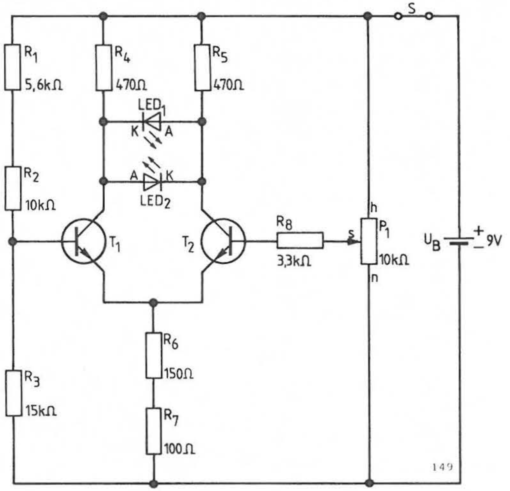

S
R1
5,6kΩ
R4
470Ω
R5
470Ω
LED1
K
A
LED2
R2
10kΩ
T1
T2
R8
3,3kΩ
s
h
P1
10kΩ
n
UB
+
9V
R6
150Ω
R3
15kΩ
R7
100Ω
149

Fig. 149 Differential amplifier

hed). If the potentiometer slide is turned backwards and forwards (input difference not equal to zero), then one or other of the LEDs will illuminate, because the difference from zero can naturally be either positive or negative. The layout in Fig. 148 demonstrates this behavior very effectively. It is possible to find out whether the voltage at the right-hand amplifier input is greater, smaller or equal to 4.5 volts.

It is possible to see without any laborious mathematical derivations that the common emitter resistance (in our case 150 and 100Ω in series) provides the circuit with its characteristics. Increasing voltage at the potentiometer slide means an increasing base current in T2, which naturally causes the collector current to increase. According to Ohm's law this causes a higher voltage drop in the emitter resistance so that the left-hand transistor becomes less conducting, since its base is connected to a fixed voltage divider. The arguments given also apply, of course, to the case where the slide voltage of P1 falls.

13.6 How full is the capacitor?

Knowledge is said to be everything. The circuit in Fig. 151 will provide you with information concerning the state of charging of the capacitor. LED1 illuminated – capacitor less than half charged; both LEDs out – capacitor half charged; LED2 illuminated – capacitor more than half charged. Press down the contact maker in the construction

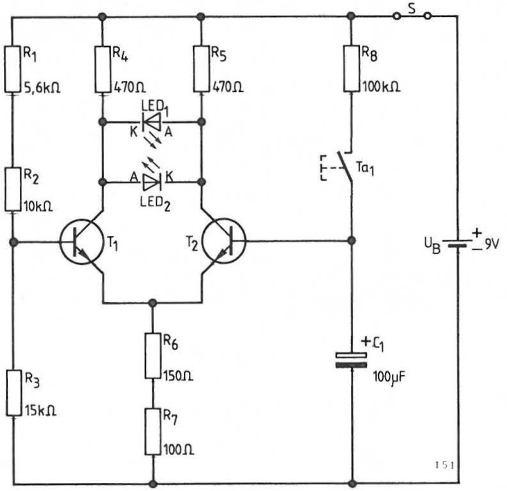
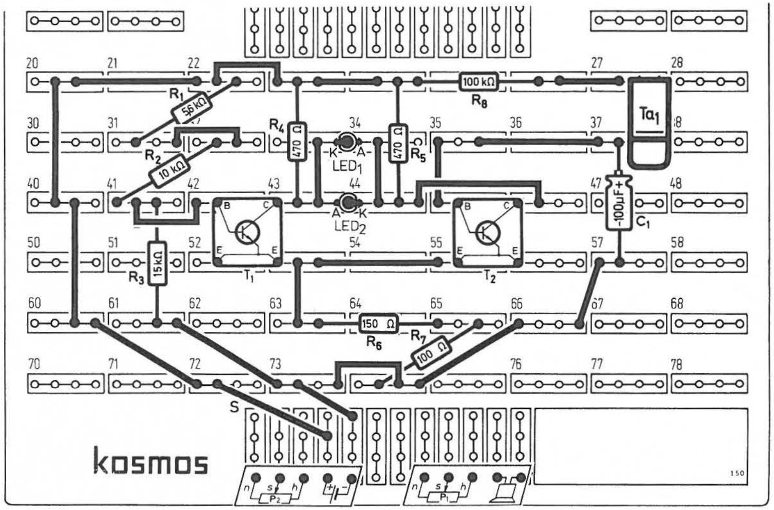

S
R1
5,6kΩ
R4
470Ω
R5
470Ω
R8
100kΩ
LED1
K
A
LED2
Ta1
R2
10kΩ
T1
T2
UB
+
9V
R6
150Ω
+C1
100µF
R3
15kΩ
R7
100Ω
151

Fig. 151 What is the state of charge of the capacitor?

Fig. 150 Construction of circuit 151


20
21
22
27
28
R1
56 kΩ
100 kΩ
R8
Ta1
30
31
R4
470 Ω
34
35
36
37
R2
10 kΩ
K
A
LED1
470 Ω
R5
40
41
42
43
44
47
48
A
K
LED2
B
C
E
100µF
C1
50
51
52
54
55
57
58
R3
15kΩ
T1
T2
60
61
62
63
64
65
66
67
68
150 Ω
R6
R7
100 Ω
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71
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73
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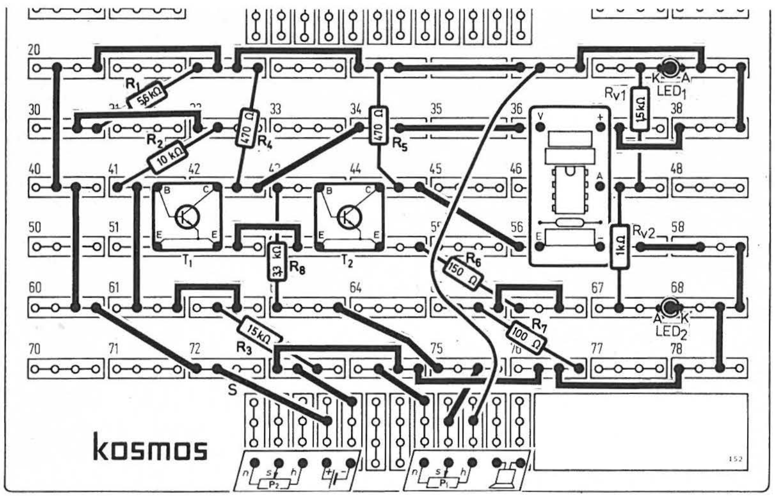
77
78
S
kosmos
n
s
h
P2
P1
150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61
64
67
68
71
72
75
77
78
R1 5,6kΩ
R2 10kΩ
470 Ω R4
470 Ω R5
Rv1 1,5kΩ
LED1
K A
V +
A
E
T1
T2
3,3 kΩ R8
R6 150 Ω
Rv2 1kΩ
R7 100 Ω
15kΩ R3
A K LED2
S
kosmos
P2
P1
n s h
152

Fig. 152 Construction of circuit 153

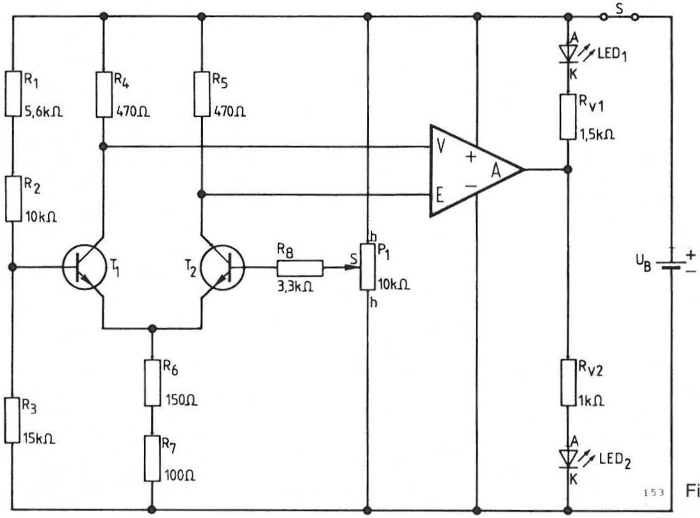

S
A
LED1
K
R1 5,6kΩ
R4 470Ω
R5 470Ω
Rv1 1,5kΩ
V +
E −
A
R2 10kΩ
T1
T2
R8 3,3kΩ
h
s
P1 10kΩ
h
UB
+
9V
R6 150Ω
Rv2 1kΩ
R3 15kΩ
R7 100Ω
A
LED2
K
153

Fig. 153 A highly sensitive comparator

according to Fig. 150 and hold it down. LED1 will go out after a certain time and after a further period LED2 will go on. If you release the contact maker you can observe the process of discharge.

13.7 A highly sensitive comparator

You have seen that the differential amplifier not only possesses two inputs it is also provided with two outputs. What do you do with two outputs? You remember our amplifier module that has two inputs – what a coincidence! – well connect the outputs of the differential amplifier to the two inputs of the amplifier module. The circuit in Fig. 153 is now, since it consists of two amplifiers, an extraordinarily sensitive comparator for “smaller – bigger – equal“ (construction diagram 152). Even the slightest changes in the setting of the potentiometer have an immediate effect on both LEDs at the output (the fact that only one output is available here is caused by a circuitry dodge inside the integrated circuit).

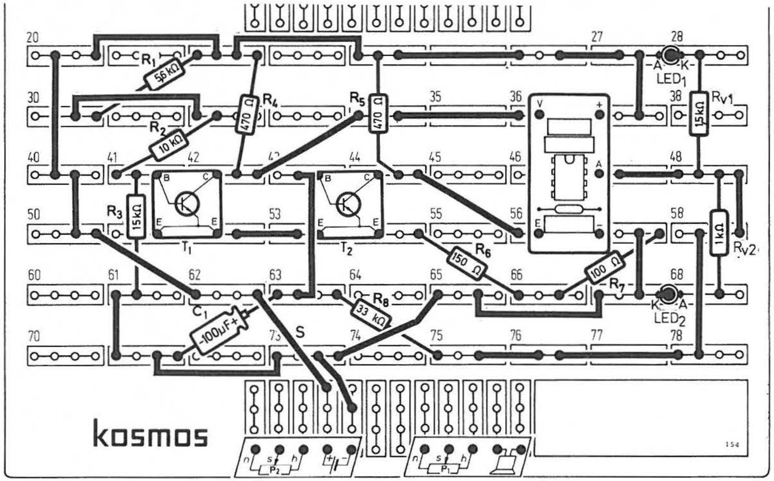
13.8 Swinging differential oscillator

You remember right at the beginning of this book you built a blinking circuit using the amplifier module without having the slightest idea what secrets were hidden inside the black box of the

IC. The veil has now been lifted a bit, the fact that there are two inputs makes you suspect (correctly) that they lead to a differential amplifier inside. We can use this knowledge to gain an insight into the blinking function; circuit 155 (construction diagram 154) leads us along the right path. The two transistors in the left-hand part are connected to form the familiar differential amplifier; an electrolytic capacitor, which can be charged and discharged via resistor *R8*, is attached to the right-hand input (the base of T2). The amplifier module output, which is initially at +9V when the battery voltage is applied to the circuit via the switch connector S, delivers the current for charging the electrolytic capacitor. You could analyze precisely what happens now in the previous experiments: When the capacitor has reached a charging voltage of ca. +4.5V (which can take a fairly long time on first switching on), then the output of the amplifier module changes from +9V to about 0V. The capacitor no longer receives any charging current; on the contrary it now discharges itself via *R8*. This continues until the voltage at the positive connection of the capacitor falls below 4.5V. Your sensitive comparator then reacts promptly and the output of the amplifier module springs up to +9V once again; the whole story then begins again from the beginning.

Experiment suggestions:

The frequency of blinking depends on *R8* and *C1*. Values of 3.3kΩ, 100kΩ and 220kΩ can be tried out for *R8* and of 100μF and 470μF for *C1* in any combination you like.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55
56
58
60
61
62
63
64
65
66
68
70
74
75
76
77
78
R1
56kΩ
R2
10 kΩ
R3
15kΩ
R4
470 Ω
R5
470 Ω
R6
150 Ω
R7
100 Ω
R8
33 kΩ
C1
100μF
S
T1
T2
B
C
E
V
A
LED1
LED2
A
K
Rv1
15kΩ
Rv2
1kΩ
kosmos
P1
P2
154

Fig. 154 Construction of circuit 155

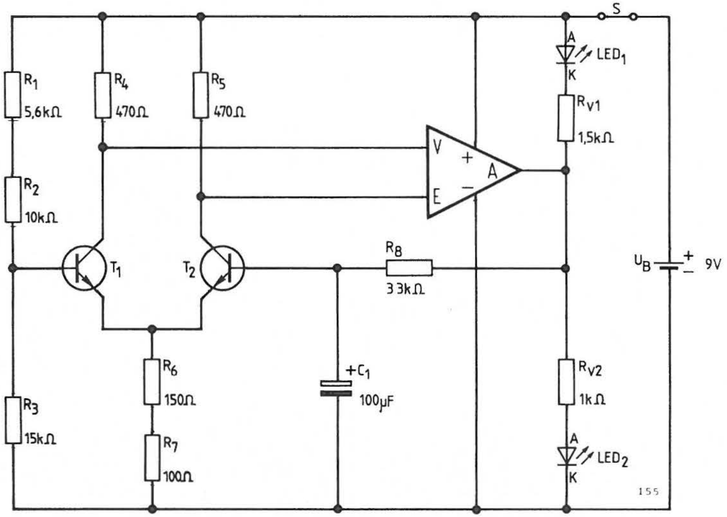

S
A
LED1
K
R1
5,6kΩ
R4
470Ω
R5
470Ω
Rv1
1,5kΩ
V
+
A
E
−
R2
10kΩ
T1
T2
R8
3,3kΩ
UB
+
9V
R6
150Ω
+C1
100μF
Rv2
1kΩ
R3
15kΩ
R7
100Ω
A
LED2
K
155

Fig. 155
The comparator becomes an oscillator circuit

13.9 Differential amplifier – and what now?

The eight-limbed integrated circuit of the amplifier module naturally contains a whole lot of other circuitry apart from the differential amplifier, but you have not yet acquired the background knowledge to understand it. But that should not worry you; what is important is that you can use this fascinating component for the craziest amplifier and non-amplifier applications.

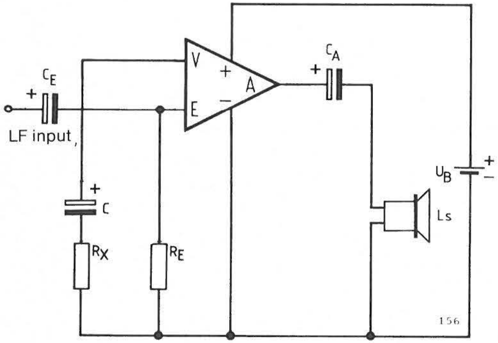


Fig. 156 The size of *Rx* determines the amplification factor

In the case of amplifier applications remember one thing – the voltage to be amplified is applied to input "E", input "V" is employed for adjusting the amplification factor. If it is "open", that is unconnected, then the amplification factor is 1. If it is connected, via a capacitor, to the negative pole of the battery then the amplification factor is about five thousand. All amplification values between one and five thousand can be obtained by including a resistor *Rx* in series with the capacitor – the lower its resistance the higher the amplification (Fig. 156).

There is a list in Table 5 of what you can apply to the two inputs and how the output behaves; you will find it useful for the little circuits that follow.

E	V	A
open	open	$U_{0\,max.}$
0 Volt	open	$U_{Batt./2}$
0 V...$U_{Batt.}$	open	$U_{Batt./2}$ ... $U_{0\,max.}$
0 V...$U_{Batt.}$	0 V	$U_{0\,max.}$
0 V...$U_{Batt.}$	0 V...$U_{Batt.}$	$U_{0\,max.}$ (E=V)
open	0 V...$U_{Batt.}$	$U_{0\,max.}$
$U_{Batt.}$	0 V...$U_{Batt.}$	$U_{0\,max.}$
0 V...$U_{Batt.}$	$U_{Batt.}$	$U_{0\,max.}$ if $E > U_{Batt.-1\,V}$ 0 V if $E < U_{Batt.-1\,V}$

$U_{0\,max.} \approx U_{Batt.-1,3\,V}$

Table 5 Output behavior of the amplifier module under various input conditions

13.10 In time – a metronome

Now we can fulfil the promise to build a metronome with an adjustable beat (circuit diagram 158). As soon as the connector S is inserted in construction 157 the apparatus begins to beat time audibly. Turn the potentiometer completely to the left and count the slow beats out like a musician "... one and ... one and ... one and". The beat rate can be increased by turning the potentiometer knob to the right.

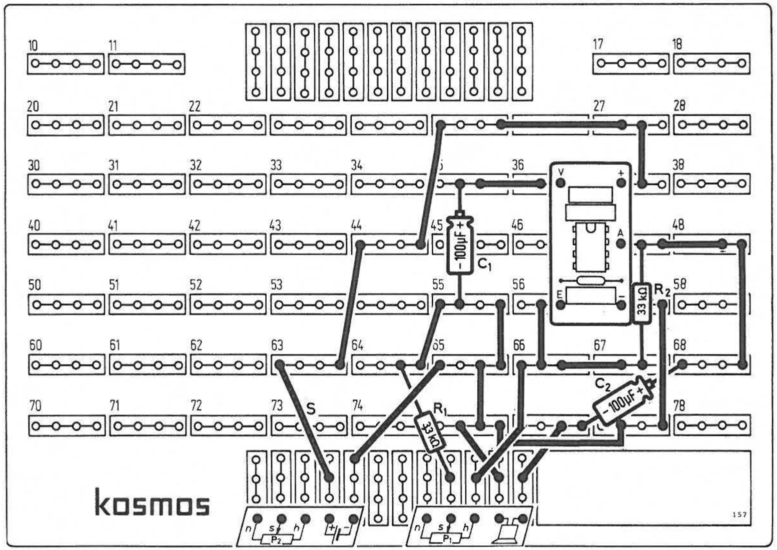
Experiment suggestions:

The metronome can be turned into a motorbike simulator merely by changing the value of *C*1 to 10μF. You can then really "give gas" with the potentiometer.

If the value of *C*1 is changed to 0.1μF (= 100nF) then you have got a deafening "hand-controlled" siren. Turn the potentiometer backwards and forwards to your heart's desire and you will create a din that drives the neighbors mad. In the next section this siren will be automated so that the "manual work" is unnecessary.

13.11 Greetings from Kojak – a fully automatic siren

At first sight circuit diagram 160 looks complicated, but if you look more closely you will see that it merely consists of two familiar basic circuits: on the left an astable multivibrator made up of two transistors and on the right one realized with the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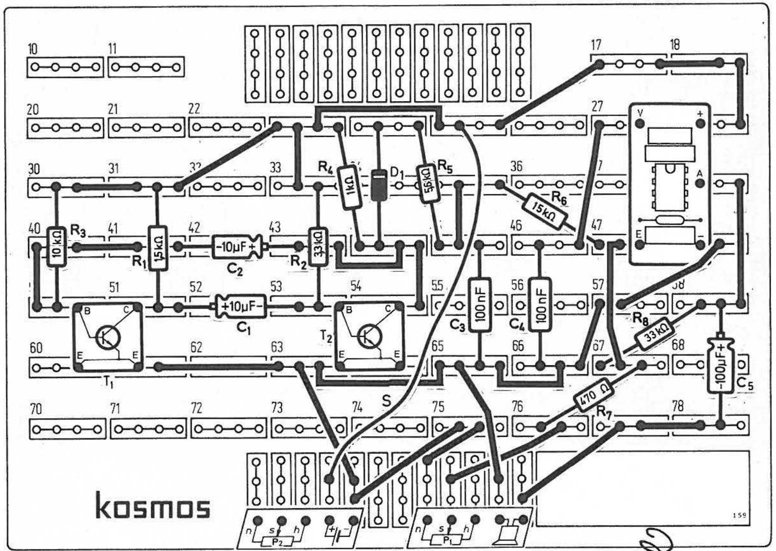
52
53
55
56
58
60
61
62
63
64
65
66
67
68
70
71
72
73
74
78
100µF
C1
V
+
A
E
33kΩ
R2
C2
100µF
S
R1
3,3kΩ
kosmos
n
s
h
P2
P1
157

Fig. 157 Construction of circuit 158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56
57
60
62
63
65
66
67
68
70
71
72
73
74
75
76
78
R4
1kΩ
D1
R5
56kΩ
R6
15kΩ
R3
10kΩ
R1
15kΩ
10µF
C2
R2
33kΩ
10µF
C1
B
C
E
T1
T2
C3
100nF
C4
100nF
R8
33kΩ
100µF
C5
470Ω
R7
S
V
+
A
E
kosmos
n
s
h
P2
P1
159

Fig. 159 Construction of circuit 160

Fig. 158 Metronome

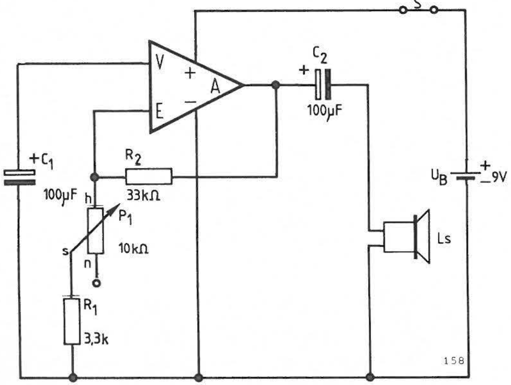
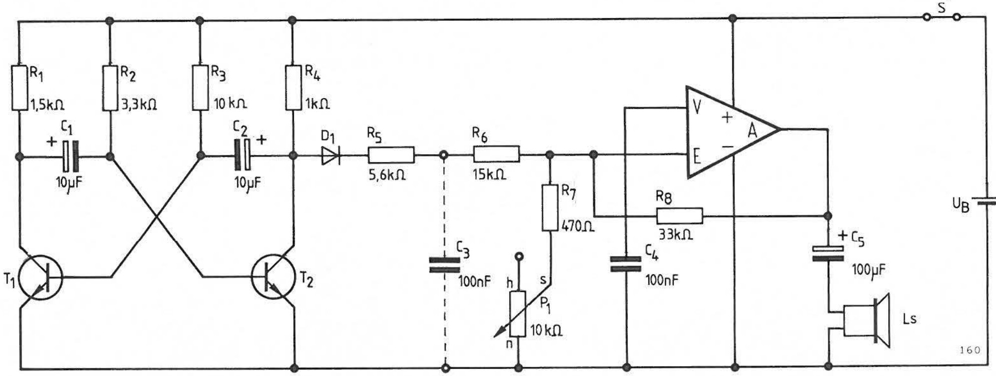

S
C2
+
100µF
V
+
A
E
–
+C1
100µF
R2
33kΩ
h
P1
10kΩ
s
n
R1
3,3k
UB
+
–9V
Ls
158

Fig. 160 Kojak siren


S
R1
1,5kΩ
R2
3,3kΩ
R3
10 kΩ
R4
1kΩ
C1
+
10µF
C2
+
10µF
D1
R5
5,6kΩ
R6
15kΩ
R7
470Ω
C3
100nF
h
s
P1
10 kΩ
n
V
+
A
E
–
R8
33kΩ
C4
100nF
+C5
100µF
Ls
UB
+
–9V
T1
T2
160

amplifier module. The two are coupled together via a diode and the two resistors *R*5 and *R*6; or put more precisely, the slower left-hand multivibrator periodically changes the pitch of the right-hand one. Potentiometer P1 can be employed to alter the overall pitch (construction diagram 159).
Experiment suggestions:
Connect the additional capacitor *C*3 shown hatched in the circuit diagram.
Exchange capacitor *C*1 for one of 100μF.
Turn round the diode so that its cathode is directed towards the collector of transistor T2.
Remove the 0.1μF (= 100nF) capacitor employed as *C*3 from the circuit again and replace it parallel to *C*4.
Combinations of the suggested changes provide ever new sound effects – you should continue experimenting until you think you have got the original Kojak sound.

13.12 An electronic harp

Circuit diagram 162 is for an instrument that may not be suitable for ambitious musical tastes, because the tolerances of the components and the standard resistances employed mean that each single note ought to be tuned by means of the potentiometer. But we do not wish to be more pedantic than is necessary, so we take hold of the "playing wire" and pass it rapidly over the "harp strings" (the contact clips marked with grey in construction diagram 161). The setting of the P1

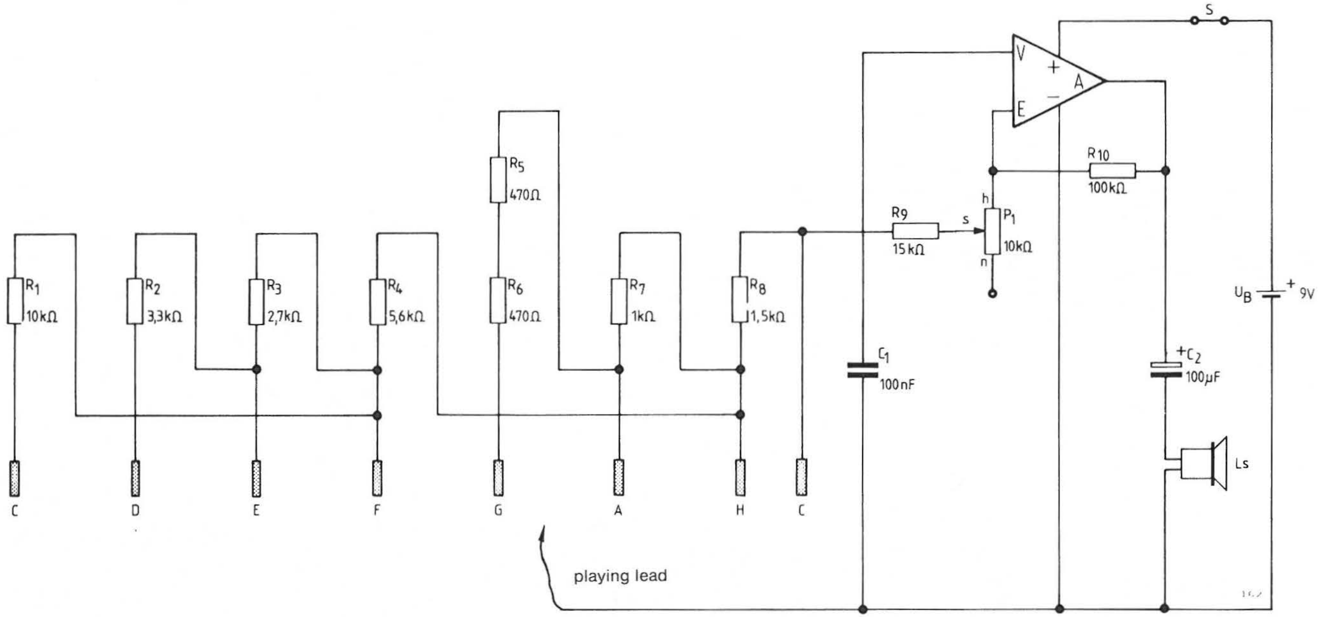


Fig. 162 Electronic "harp"

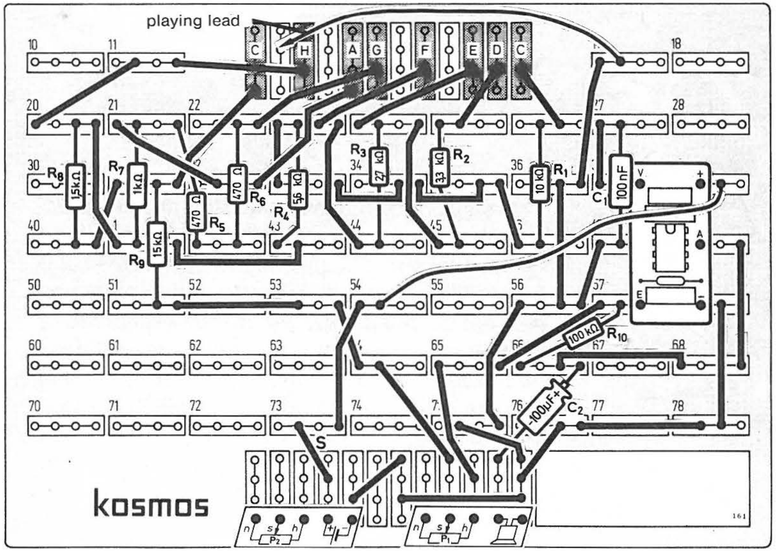

playing lead
C
H
A
G
F
E
D
C
R8
15kΩ
R7
1kΩ
R9
15kΩ
470 Ω
R5
470 Ω
R6
R4
56 kΩ
R3
27 kΩ
33 kΩ
R2
10 kΩ
R1
100 nF
C1
100 kΩ
R10
100µF
C2
S
kosmos
P2
P1
161

Fig. 161 Construction of circuit 162

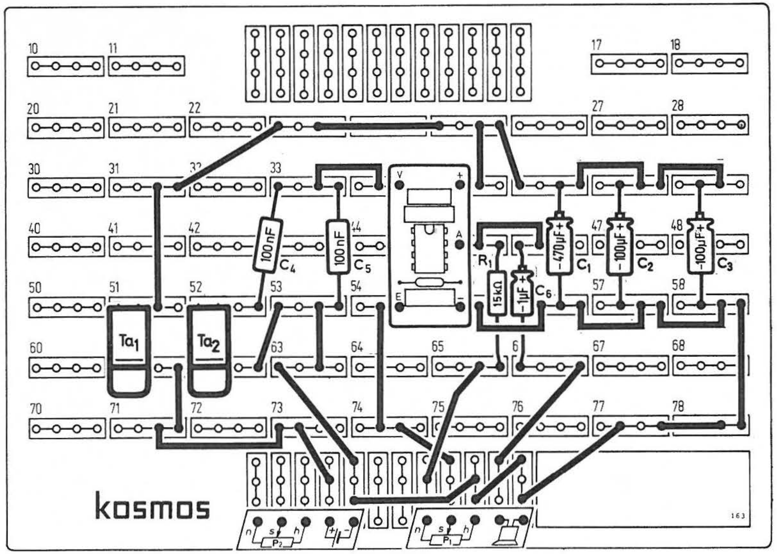

Ta1
Ta2
100nF
C4
100nF
C5
R1
15kΩ
1µF
C6
470µF
C1
100µF
C2
100µF
C3
kosmos
P2
P1
163

Fig. 163 Construction of circuit 164

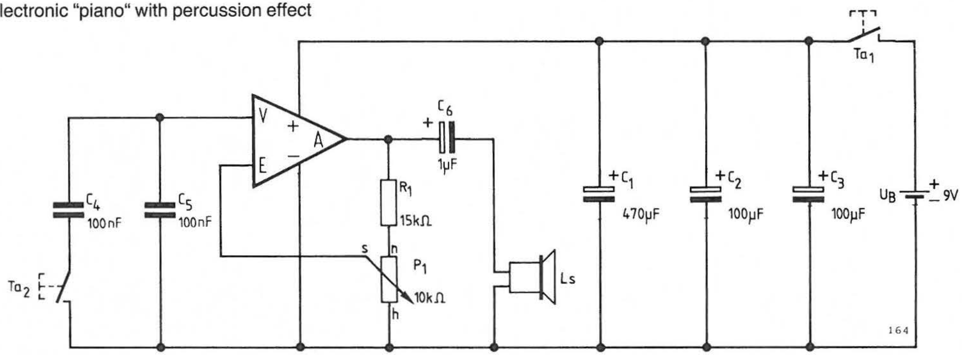
affects the overall pitch, as well as the relationship of the notes to each other.

13.13 Percussion – the magic word for the piano

Percussion includes the noise that is produced when a hammer strikes a string and produces a definite note with an (almost inimitable) resonance.

Our "electronic piano" in Fig. 164 (construction 163) gives some idea of this, in that it at least produces some sort of imitation of this when contact maker Ta1 is pressed. The pitch of the "piano"

Fig. 164 Electronic "piano" with percussion effect


Ta1
V
+
A
E
–
C6
+
1µF
R1
15kΩ
s
h
P1
10kΩ
h
Ls
C4
100nF
C5
100nF
Ta2
+C1
470µF
+C2
100µF
+C3
100µF
UB
+
–
9V
164

can be preset by means of potentiometer P1, contact maker Ta2 alters the overall pitch. Capacitors *C*1,*C*2 and *C*3 are responsible for the decay of the notes.

You are allowed to play it...

13.14 Separate paths for high and low notes – a two-channel light organ

Some people are driven wild by the crazy lighting effects produced in discotheques. Let us look at the phenomenon more soberly and try to find out why different lamps light up with high notes than with low.

Circuit 166 goes a long way towards explaining the secret. It contains two networks of resistors and capacitors (in the grey sections of circuit diagram 166), of which the one labelled T reacts mainly to low notes and the one labelled H mainly to high ones. The functioning of such a network, that is known as a *filter*, depends, on the one hand, on the fact that the "alternating current resistance" sinks as the frequency is increased (higher note) and, on the other hand, on the time constants of the interactions between capacitors and resistors. Such filters can be used to filter different frequencies from a mixture of frequencies, which is what every piece of music consists of.

Fig. 165 Construction of circuit 166

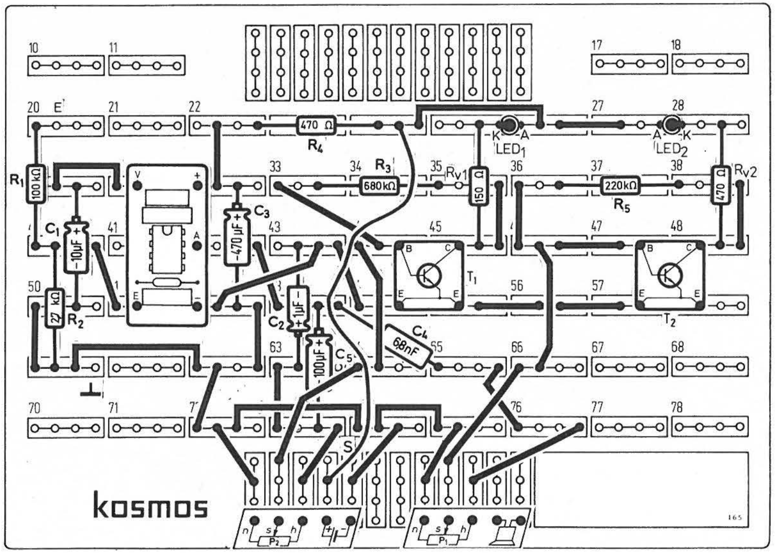
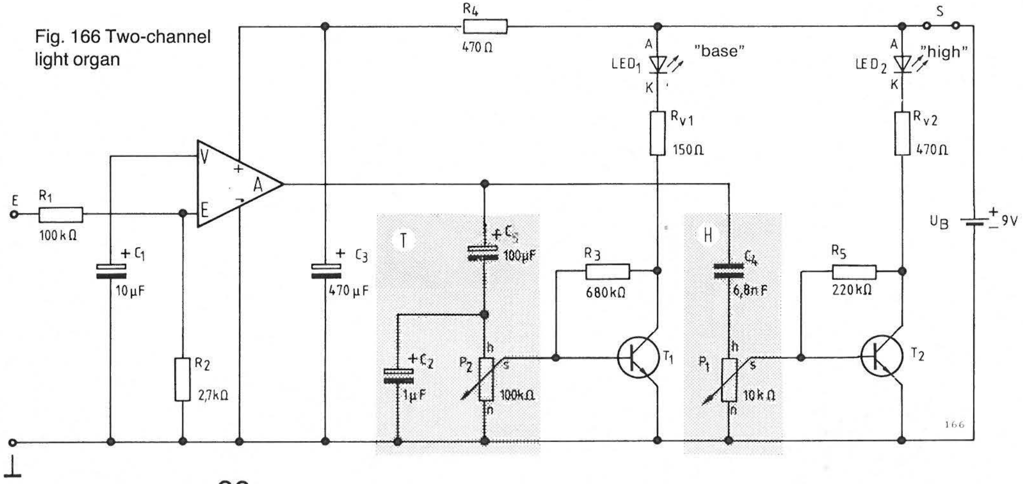

10
11
17
18
20 E
21
22
27
28
470 Ω
R4
K A
LED1
A K
LED2
R1
100 kΩ
33
34 R3
680 kΩ
35 Rv1
150 Ω
36
37
220 kΩ
R5
38
470 Ω
Rv2
V
+
A
E
C1
10 µF
41
C3
470 µF
43
45
47
48
B C
T1
E E
B C
T2
50
27 kΩ
R2
1
C2
1 µF
56
57
C4
68 nF
63
100 µF
C5
65
66
67
68
70
71
76
77
78
S
kosmos
n s h
P2
P1
165

Fig. 166 Two-channel light organ


R4
470 Ω
S
A
LED1
K
"base"
A
LED2
K
"high"
Rv1
150 Ω
Rv2
470 Ω
V
+
A
E
−
E
R1
100 kΩ
+ C1
10 µF
R2
2,7 kΩ
+ C3
470 µF
T
+ C5
100 µF
+ C2
1 µF
P2
h
s
n
100 kΩ
R3
680 kΩ
T1
H
C4
6,8 nF
P1
h
s
n
10 kΩ
R5
220 kΩ
T2
UB
+
9V
166

If the input E of construction 165 is connected to the diode output of a cassette recorder or with the loudspeaker output of a transistor radio, then the two LEDs go on and off depending on the proportion of low notes and high notes in the output.

13.15 Low notes – long range

Seafarers are not easily put out by warning sirens and certainly not by alarm sirens such as are employed on land by the fire brigade.
Nevertheless ships always give warning signals with a particularly low note. The solution of the riddle is that low notes have a significantly longer range than high ones if there is nothing in the way (and that is usually the case at sea).

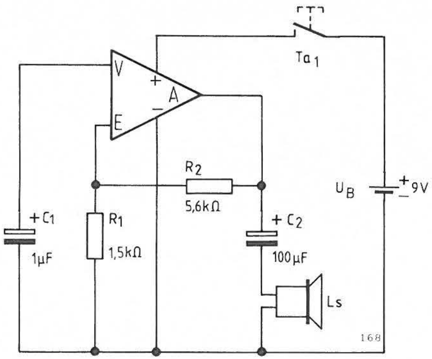
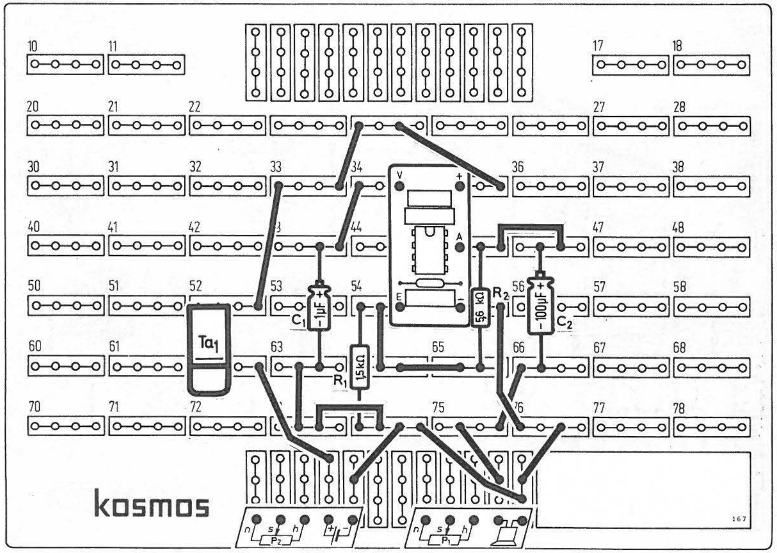

Ta1
V
E
A
+
−
R2
5,6kΩ
+C1
1µF
R1
1,5kΩ
+C2
100µF
Ls
U_B
+9V
168

Fig. 168 Ship's siren

A ship's siren that you could perhaps build into a model boat is constructed according to Fig. 167 (circuit diagram 168). A press on the contact maker and the loudspeaker "roars out" a deep note that freezes the marrow in your bones.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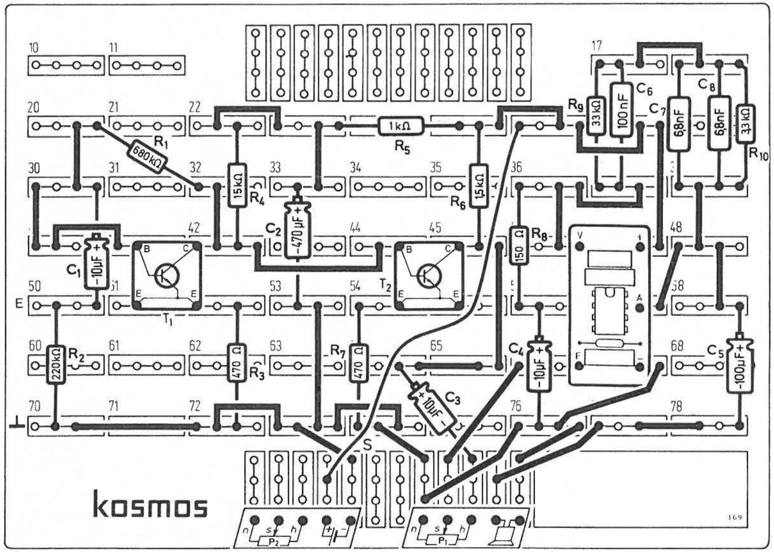
54
56
57
58
60
61
63
65
66
67
68
70
71
72
75
76
77
78
V
+
A
E
Ta1
C1
1µF
R1
15kΩ
56kΩ
R2
100µF
C2
kosmos
P2
P1
n
s
h
167

Fig. 167 Construction of circuit 168

13.16 Distorted reproduction of phonograph records

When a record is cut there are problems caused by the mechanical state of the record-cutting apparatus and the material of the record. It is not possible to discuss the details here in this experiment book, but this much can be said – in order to overcome the difficulties of recording, the frequency range of the music is limited by suitable filters, that is deliberately distorted. However, when the record is played it is necessary to undertake the reverse process, that is to correct the distortion.
Circuit diagram 170 shows a record player amplifier with distortion correction. It is constructed according to Fig. 168; a record player with a magnetic system can be attached to input E. But you should remember that the little loudspeaker which we are using here cannot possibly act as a substitute for a loudspeaker box!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44
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53
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60
61
62
63
65
68
70
71
72
76
78
17
R1 680kΩ
R2 220kΩ
R3 470 Ω
R4 15kΩ
R5 1kΩ
R6 15kΩ
R7 470
R8 150 Ω
R9 33kΩ
R10 33kΩ
C1 10µF
C2 470µF
C3 10µF
C4 10µF
C5 100µF
C6 100nF
C7 68nF
C8 68nF
T1
T2
B C E
V + A F
E
S
kosmos
n s h P2
n s h P1
169

Fig. 169 Construction of circuit 170

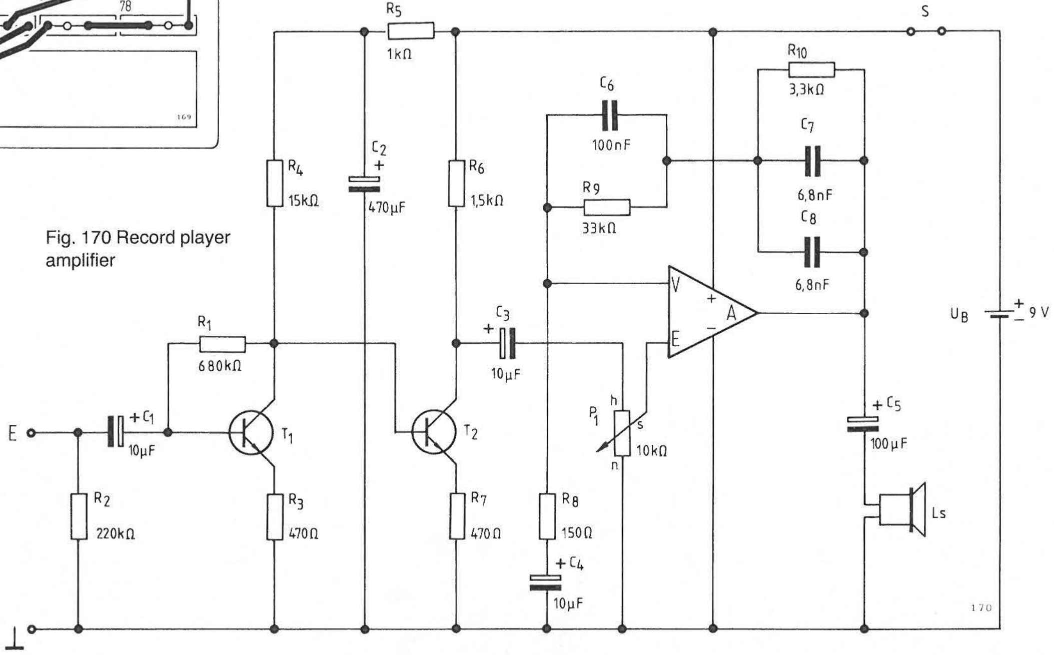

R5
1kΩ
S
R10
3,3kΩ
C6
100nF
C7
6,8nF
C8
6,8nF
R9
33kΩ
C2
+
470µF
R4
15kΩ
R6
1,5kΩ
V
+
A
−
E
UB
+ 9 V
−
C3
+
10µF
R1
680kΩ
E
+C1
10µF
T1
T2
P1
h
s
n
10kΩ
+C5
100µF
Ls
R2
220kΩ
R3
470Ω
R7
470Ω
R8
150Ω
+C4
10µF
170

Fig. 170 Record player amplifier

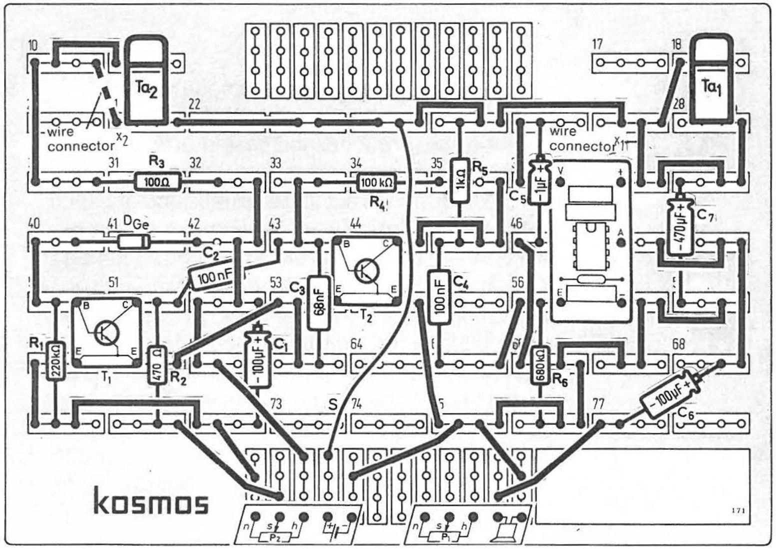

10
Ta2
22
wire connector x2
31
R3
100Ω
32
33
34
100 kΩ
R4
35
1kΩ
R5
C5
1µF
wire connector x1
17
18
Ta1
28
470µF
C7
40
41 DGe
42
C2
100nF
43
44
46
B
C
E
T2
51
53
C3
68nF
100nF
C4
56
R1
220kΩ
T1
470Ω
R2
100µF
C1
64
680kΩ
R6
68
100µF
C6
73
S
74
77
kosmos
P2
P1
171

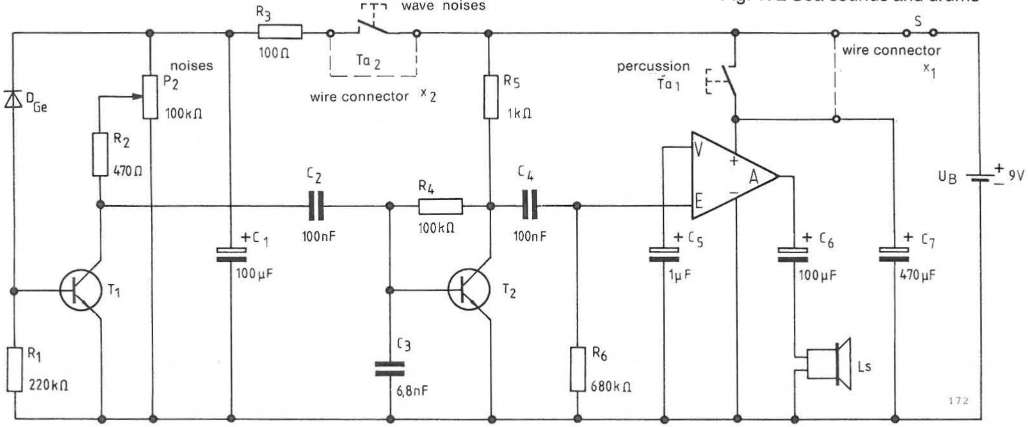
Fig. 171 Construction of circuit 172

13.17 Noisy success...

is possible in the truest sense of the word if you connect an ordinary germanium diode in the wrong direction to your 9V power supply. The allowed reverse voltage of this diode would then be exceeded and it would "break through" i.e. a considerable current would flow in the reverse direction. However, by using a suitable high protective resistance you can make sure that this "breakthrough" does not cause any lasting damage and, at the same time, exploit a pretty effect, which this breakthrough current bestows on us. Very irregular electron migration takes place (statistical distribution, which will be discussed further in Section 21.16), whose irregularities can be amplified and heard at the loudspeaker, as what is known as **noise**.

You are now going to exploit the phenomenon of noise, for which hi-fi freaks have no particular liking, and construct a noise generator according to Fig. 171 (circuit diagram 172 – the wire connector x2 shown hatched in the construction diagram is not connected at first). Press down the contact maker Ta2 and so adjust potentiometer P2 that a powerful noise can be heard. By regularly depressing and releasing contact maker Ta2, it is possible to make a sound like that of waves breaking on a beach.

Fig. 172 Sea sounds and drums


R3
100Ω
wave noises
Ta 2
wire connector x2
noises
P2
100kΩ
DGe
R2
470Ω
C2
100nF
R4
100kΩ
R5
1kΩ
C4
100nF
percussion
Ta1
S
wire connector
x1
V
A
E
+
−
UB
+ 9V
+C1
100µF
T1
T2
C3
6,8nF
R6
680kΩ
+ C5
1µF
+ C6
100µF
+ C7
470µF
Ls
R1
220kΩ
172

13.18 Drum sounds from the germanium diode

A diode operating in the reverse direction is able to imitate the sound of a brush on a drum. To do this the construction in Fig. 171 is reorganized by removing wire connector x1 and inserting wire connector x2.
Pressing contact maker Ta1 results in a noise that sounds very like a drum.

Batteries still o.k.?
?

13.19 Electronic roulette "heads or tails"

Let us now relax and play a little game – electronics has long gained a place in every gaming den in the world. When you press the contact maker of our construction (Fig. 173, circuit diagram 174), then both LEDs light up with a diminished brightness; they are being rapidly switched on and off, so that the eye only notices a flickering. Now leave go of the contact maker – one LED will remain lit. Will it be the left? Will it be the right? Nobody can prophesy. If you bet with an opponent which LED will be "heads" and which "tales" you can have a ball.
The left-hand side of the circuit with the amplifier module is an astable multivibrator, which switches the right-hand part of the circuit, which is the special flip-flop from Section 11.5, at a frequency of about ten impulses per second. This frequency is way over everyone's reaction time and it is completely impossible to cheat.

Fig. 173 Construction of circuit 174

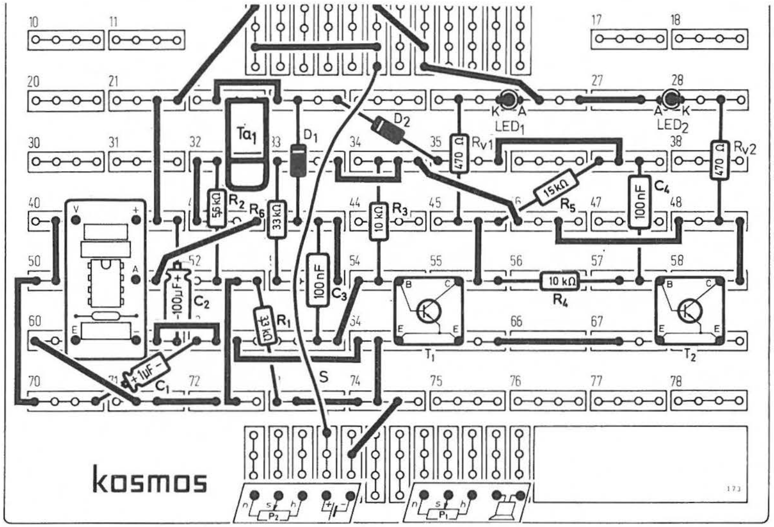
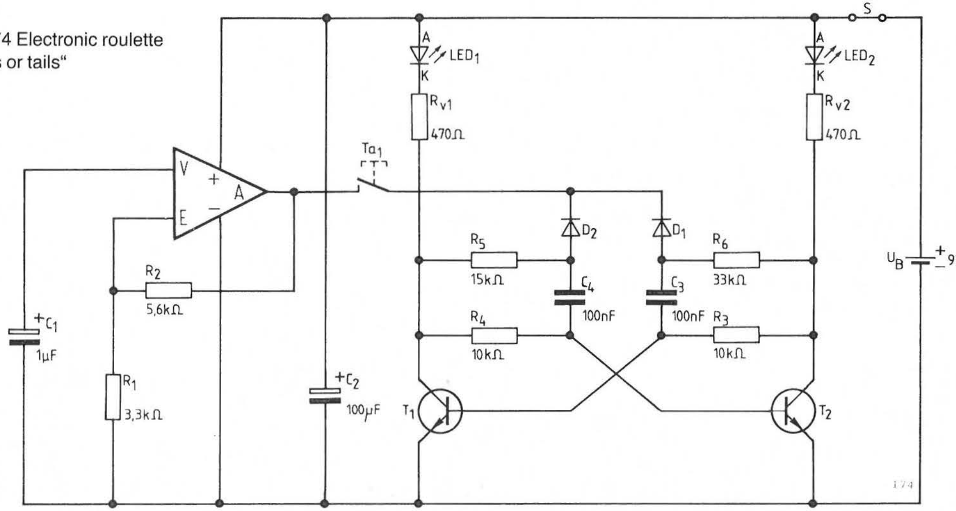

Ta1
D1
D2
LED1
LED2
K
A
Rv1
Rv2
470 Ω
R2
5,6kΩ
R6
33kΩ
R3
10 kΩ
R5
15kΩ
C4
100nF
R1
3,3kΩ
C2
100µF
C3
100nF
C1
1µF
R4
10 kΩ
T1
T2
B
C
E
S
V
kosmos
P2
P1

Fig. 174 Electronic roulette "heads or tails"


S
LED1
LED2
A
K
Rv1
470Ω
Rv2
470Ω
Ta1
V
E
A
+
–
D2
D1
R5
15kΩ
R6
33kΩ
C4
100nF
C3
100nF
R4
10kΩ
R3
10kΩ
R2
5,6kΩ
R1
3,3kΩ
+C1
1µF
+C2
100µF
T1
T2
UB
+
9V

13.20 An electronic baby-sitter

Electronics should make people's lives easier. What about a listening device, which keeps parents informed the whole time about what is going on in the nursery? Our device is put alongside baby's cot (the loudspeaker is employed as a microphone), the earphone is attached by means of two long wires (perhaps you have a second loudspeaker to hand?), and the parents can sit peacefully in their room, without the little one being "out of earshot". The earphone can naturally be attached directly for testing purposes.

Circuit diagram 176 shows that the listening device consists of two transistor amplifiers with the amplifier module for final amplification. The sensitivity can be adjusted as necessary by means of P1. If there is a powerful radio transmitter in the neighborhood then it is possible that you will also be an unwilling listener to the evening program. The only thing that will help here is "shielding", that is fitting the device into a tin box, which you must then connect to ground, the negative pole of the battery.

Suggestions for experiment:

The set is so sensitive that you can deliberately set up the "acoustic feedback" that everyone hates so much; hold the earphone with its opening downwards over the loudspeaker. You will immediately hear an unpleasant whistling noise!

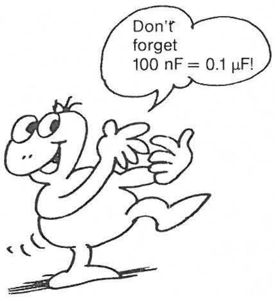

Don't forget 100 nF = 0.1 µF!

Fig. 175 Construction of circuit 176

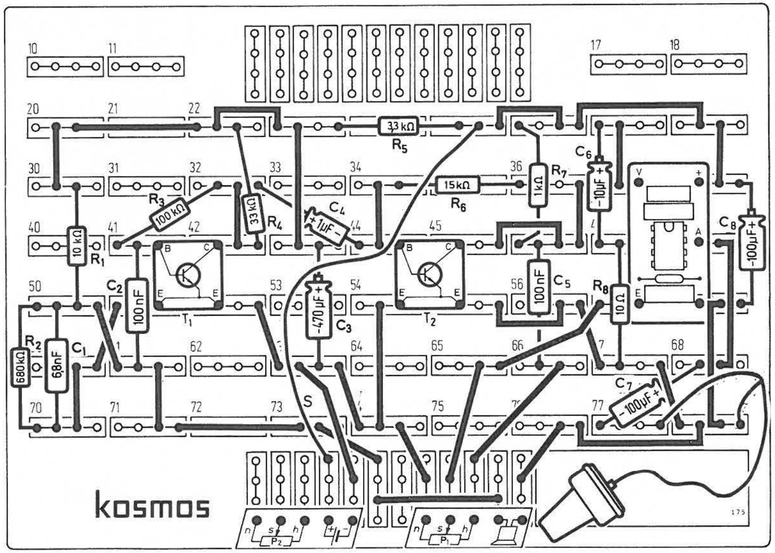
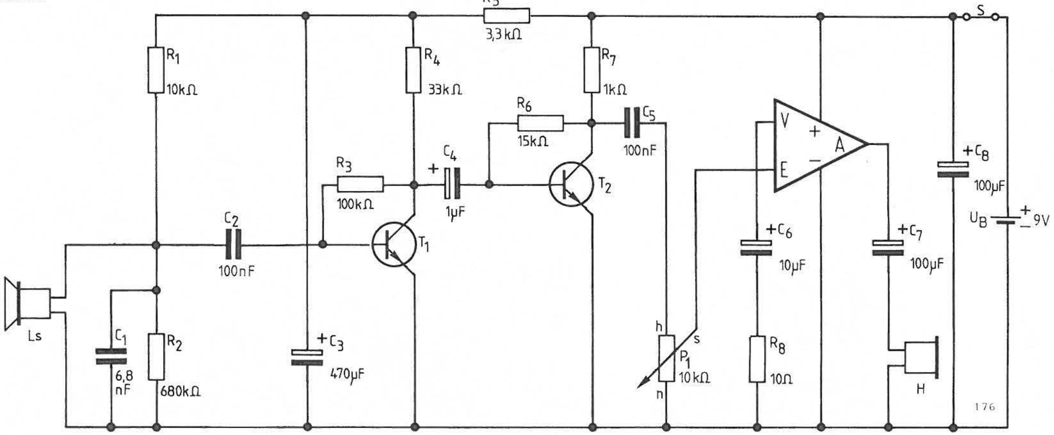

10
11
17
18
20
21
22
30
31
32
33
34
36
40
41
42
44
45
50
53
54
56
62
64
65
66
68
70
71
72
73
75
77
33 kΩ
R5
R3
100 kΩ
33 kΩ
R4
C4
+ 1µF -
15 kΩ
R6
1 kΩ
R7
C6
+ 10µF -
C8
-100µF+
10 kΩ
R1
C2
100nF
T1
T2
B
C
E
-470 µF+
C3
100nF
C5
R8
10 Ω
R2
680 kΩ
68nF
C1
C7
- 100µF +
S
V
A
E
kosmos
P2
P1
n
s
h
175

Fig. 176 Electronic baby-sitter device


R5
3,3 kΩ
S
R1
10kΩ
R4
33kΩ
R7
1kΩ
R6
15kΩ
C5
100nF
R3
100kΩ
C4
1µF
T1
T2
C2
100nF
V
A
E
+C8
100µF
UB
+
9V
+C6
10µF
+C7
100µF
Ls
C1
6,8 nF
R2
680kΩ
+C3
470µF
h
s
n
P1
10 kΩ
R8
10Ω
H
176

13.21 Amplifiers as monoflops and flip-flops

It will not have escaped your notice that electronics designers are particularly ingenious people. One of their strengths is their ability to employ unconventional methods and to use components and circuits for purposes other than those which the manufacturer originally envisaged. The amplifier module is the best example of this, it can – if you think about it for a moment – be easily employed as an astable, bistable or monostable multivibrator. You are already familiar with the "astable other use", so now let us look at the two other applications mentioned.

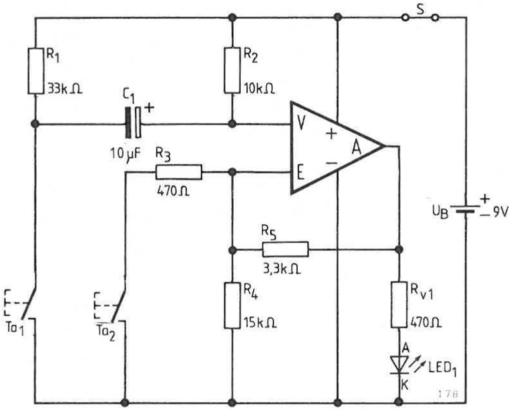

S
R1
33kΩ
R2
10kΩ
C1
+
10µF
R3
470Ω
V
+
A
E
−
R5
3,3kΩ
R4
15kΩ
Rv1
470Ω
A
LED1
K
UB
+
−9V
Ta1
Ta2
178

Fig. 178 Amplifier module as flip-flop

Figure 178 shows the circuit of a flip-flop with setting and resetting contact makers (construction Fig. 177). It has already been employed once in Section 11.19 for the noise circuit. You will find no difficulty in understanding it using the information in Table 5.

You can see in Fig. 180 (construction diagram 179) how the amplifier module can be made to operate as a monoflop. The mono time depends on *R*3 and *C*2.

Suggestion for experiment:

Various values can be tried out for *R*3 and *C*2; this makes it possible to adjust the mono time over a very wide range.

Fig. 177 Construction of circuit 178

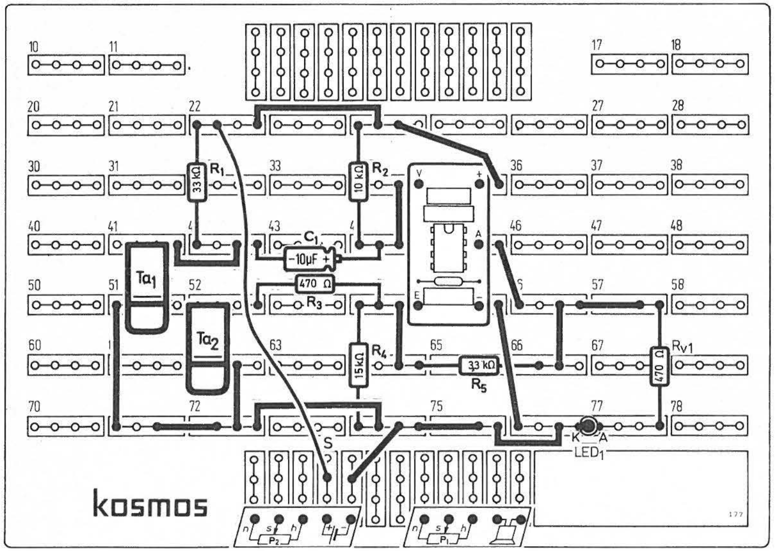
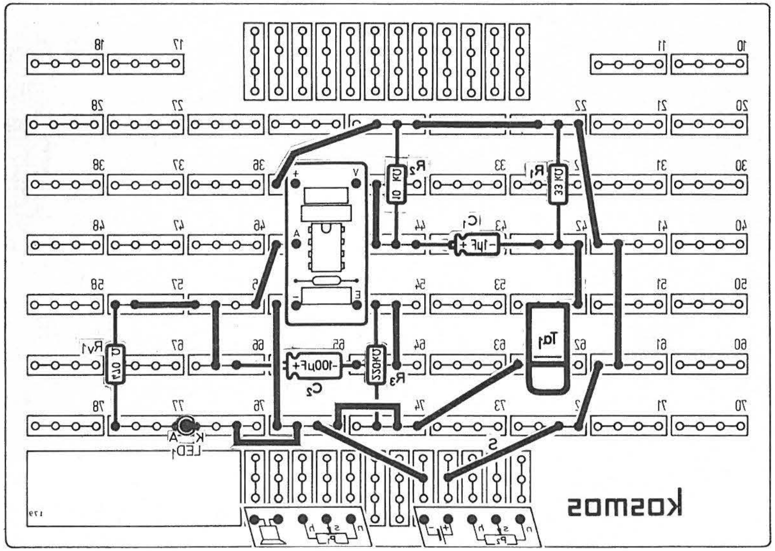

R1
33 kΩ
R2
10 kΩ
C1
-10µF +
470 Ω
R3
R4
15 kΩ
33 kΩ
R5
Ta1
Ta2
V
+
A
E
S
Rv1
470 Ω
K
A
LED1
kosmos
177

Fig. 179 Construction of circuit 180



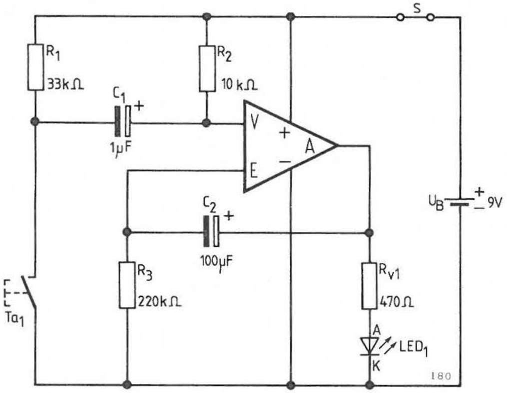


Fig. 180 Amplifier module as monoflop

14. Opto-electronics

14.1 Cold light

In contrast to the incandescent lamp that everyone is familiar with, where the light is produced by means of a very high temperature (2000 degrees Celsius and more), light-emitting semiconductors work at absolutely normal temperatures – they are only slightly above room temperature under normal working conditions.

14.2 Energy transformation

Light is a form of energy and, as you know, energy can be transformed from one form to another; potential into kinetic energy, mechanical into thermal energy (frictional heat), thermal into electrical energy (thermo elements), chemical into electrical energy (battery), magnetic into electrical energy etc. The energy is never lost, it only appears in differing forms.

14.3 The high-altitude flight of the electron

Just as a stone you have taken up onto the roof possesses potential energy and this can be visibly changed into kinetic energy when you drop it, so can an electron be lifted to a "higher level" by giving it energy – e.g. by placing it in an electrical field. When it "falls back" the energy is released again, e.g. in the form of visible or infrared light. The mechanism of action of the LED and the infrared diode depends on this transformation of energy back and forth.

Put simply it can be imagined that a "quantum" of light is emitted every time an electron falls into a hole (Fig. 181). The color of the light, i.e. the wavelength of the light emitted, depends on the type of semiconductor employed; gallium arsenide phosphide is usual for red LEDs and gallium arsenide for infrared diodes.

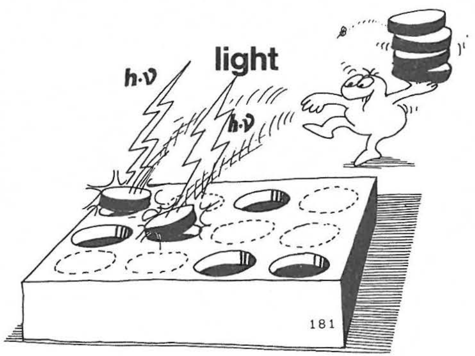


Fig. 181 The recombination of an electron with a hole produces a light quantum (h · ν).

14.4 Light receivers

Infrared radiation cannot be detected by the human eye, its wavelength lies outside the visible range (see Table 6). This does not cause any problems for electronic detectors; the phototransistor employed in the following experiments is, for example, especially sensitive in the infrared region. The mechanism of action of the phototransistor involves the transformation of energy in the reverse direction; the light falling on the base layer drags electrons from their normal places leaving behind holes and free electrons (Fig. 182), which then combine to provide the base current and – just as in a normal transistor – effect a larger collector-emitter current.

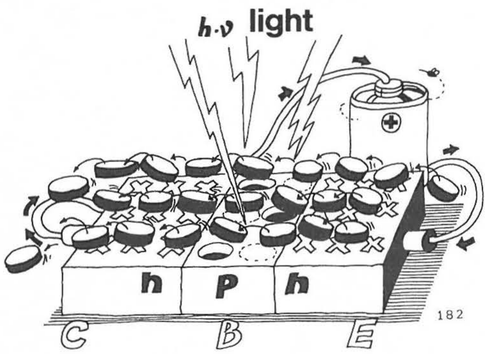

h·ν light
h
P
h
C
B
E
182

Fig. 182 The arriving light energy sets charge carriers free.

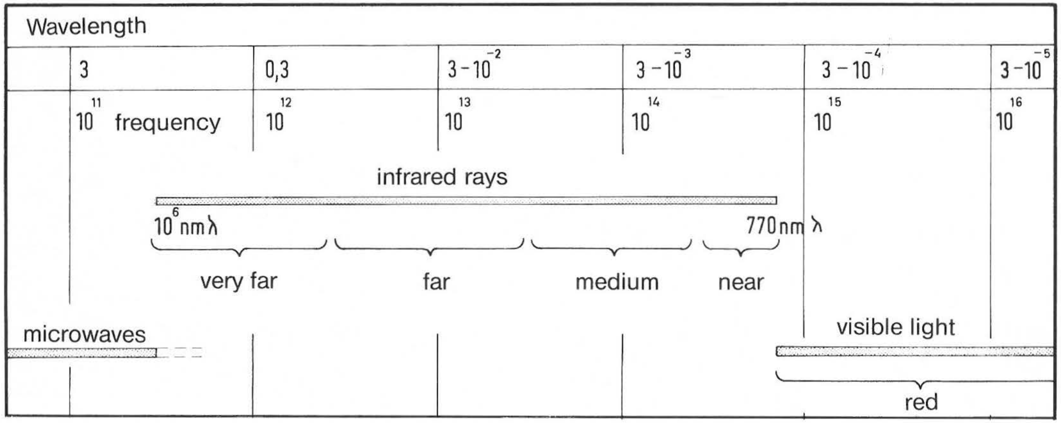

Wavelength
3
0,3
$3-10^{-2}$
$3-10^{-3}$
$3-10^{-4}$
$3-10^{-5}$
10^{11} frequency
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
infrared rays
10^{6} nm λ
770nm λ
very far
far
medium
near
microwaves
visible light
red

Table 6 Wavelengths of infrared radiation

14.5 Light controls current

Look at the phototransistor (which component is the phototransistor and which the IR diode, you have already found out in Section 11.9); it only possesses two connections (!), none is attached to the base, because this is activated by light.

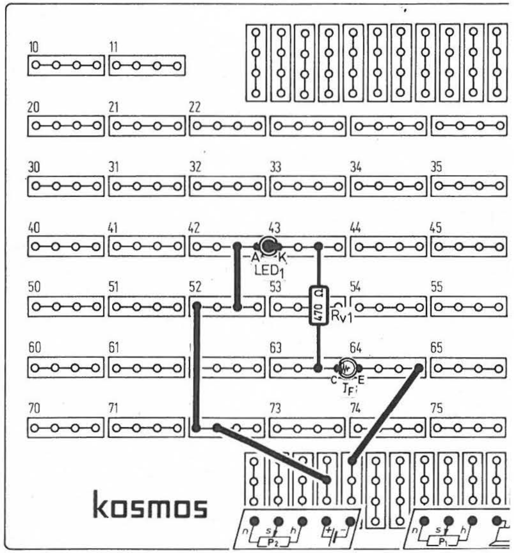
The first simple test circuit (circuit diagram 184, construction diagram 183) should make us familiar with the function of a phototransistor. A LED with its protective resistor is connected to the collector lead in order to give an indication of when a current is flowing; with moderate room lighting the LED will only be faintly illuminated or not lit at all; only when the light of a flashlamp or table lamp is directed onto the phototransistor *from above* will the collector current be so great that the LED lights up. So you have been able to establish that the phototransistor reacts to normal light, although – as previously mentioned – it is particularly sensitive to infrared light.

14.6 Invisible rays

In order to test the interaction between the IR diode and the phototransistor first bend their leads at right angles as illustrated in Fig. 185 and then set up the circuit in Fig. 187 (construction Fig. 186).

Press down the contact maker (only for a short time please to save the battery!) and, as expected, the LED will go on. The IR diode produces

Fig. 183 Construction of circuit 184


10
11
20
21
22
30
31
32
33
34
35
40
41
42
43
44
45
A
K
LED1
50
51
52
53
54
55
470 Ω
Rv1
60
61
63
64
65
C
E
TF
70
71
73
74
75
kosmos
P2
P1

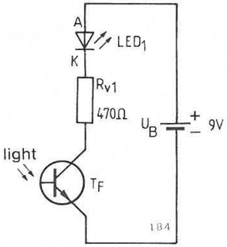

A
LED1
K
Rv1
470Ω
UB
+
9V
light
TF
184

Fig. 184
Light controlling current

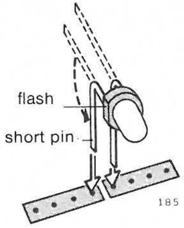

flash
short pin
185

Fig. 185 Bend the connections of the phototransistor and the IR diode at right angles.

(invisible) light, the base of the phototransistor is activated and a collector current flows. Do a blank experiment by placing a piece of black card between the IR diode and the phototransistor and then press the contact maker; nothing will happen, because the infrared light has been stopped. You have constructed a simple infrared light relay with only six components!

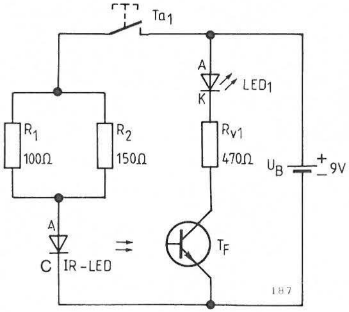

Ta1
A
LED1
K
R1
100Ω
R2
150Ω
Rv1
470Ω
UB
+
9V
A
C
IR-LED
TF
187

Fig. 187 First experiment with infrared radiation

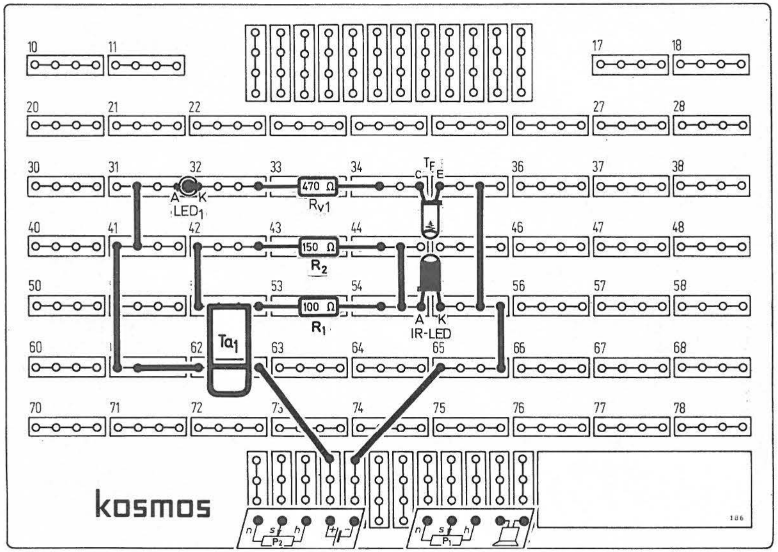

10
11
17
18
20
21
22
27
28
30
31
32
33
34
36
37
38
A
K
LED1
470 Ω
Rv1
TF
C
E
40
41
42
43
44
46
47
48
150 Ω
R2
50
53
54
56
57
58
100 Ω
R1
A
K
IR-LED
Ta1
60
62
63
64
65
66
67
68
70
71
72
73
74
75
76
77
78
kosmos
P2
P1
186

Fig. 186
Construction of circuit 187

14.7 Amplifying light

A correction must be made here straight away, because it is not light itself that will be amplified but its effects on the phototransistor. This is done in Fig. 188 by another transistor in a Darlington circuit. The light detector is now so sensitive that you will have to work in a darkened room, so that the LED is not illuminated under normal lighting conditions. However, the distance between the IR diode and the phototransistor can be greatly increased – you will see in further experiments what astonishing distances are possible.

14.8 Electronic magic

Can you light a lamp with a match?
That seems pretty stupid, it is too because you can. You can use circuit 191 (construction Fig. 190) to make a name for yourself amongst your friends as a magician. The apparatus is operated in a darkened room – nothing will happen. Only when you frighten away the spirits of the night with a spell, light a match and hold it near the phototransistor, does the light go on – and this is the hit – it stays on even when you blow out the match.
The trick can be carried out to even greater effect if you use the KOSMOS mains switching apparatus X (see the end of the book). A miserable little match can then be employed to switch on a table

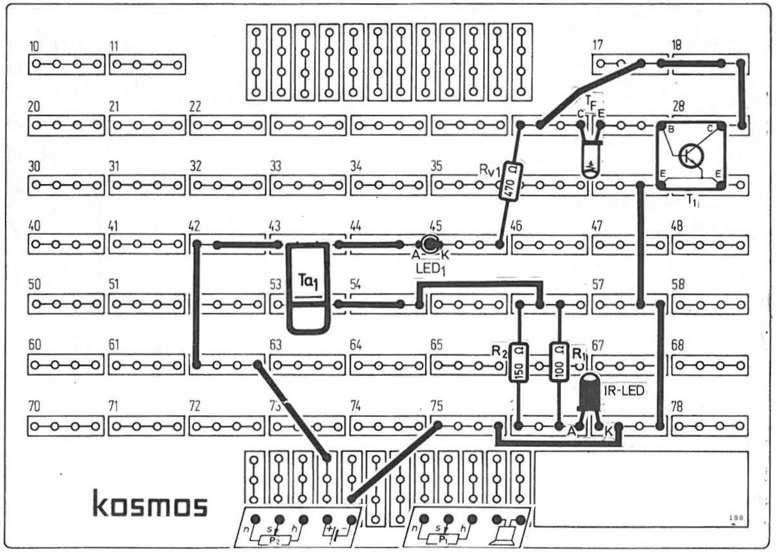
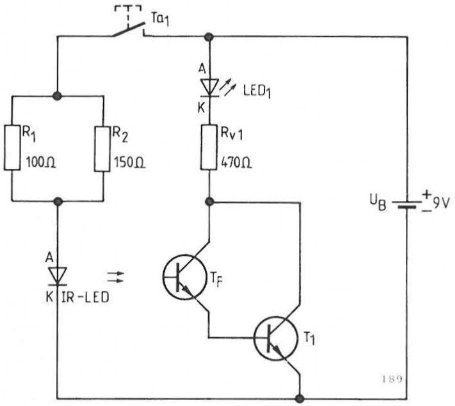

kosmos
Ta1
LED1
A
K
Rv1 470 Ω
TF
C
E
B
T1
R2 150 Ω
R1 100 Ω
IR-LED
P2
P1
188

Fig. 188 Construction of circuit 189

Fig. 189 A "light amplifier"


Ta1
A
LED1
K
R1
100Ω
R2
150Ω
Rv1
470Ω
UB
+
9V
A
K
IR-LED
TF
T1
189

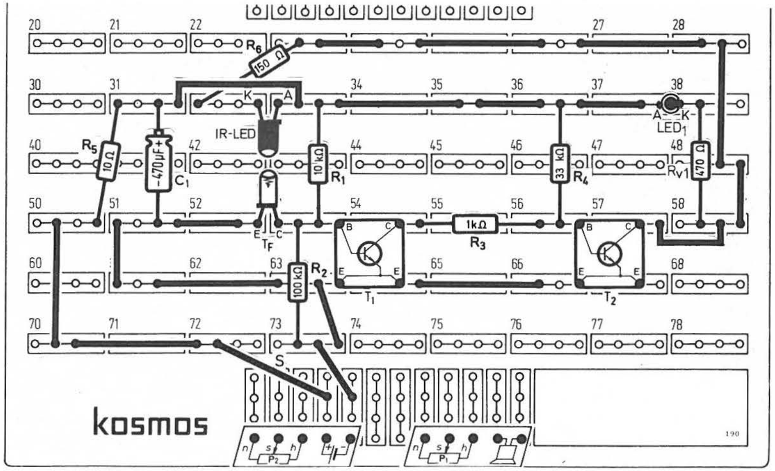
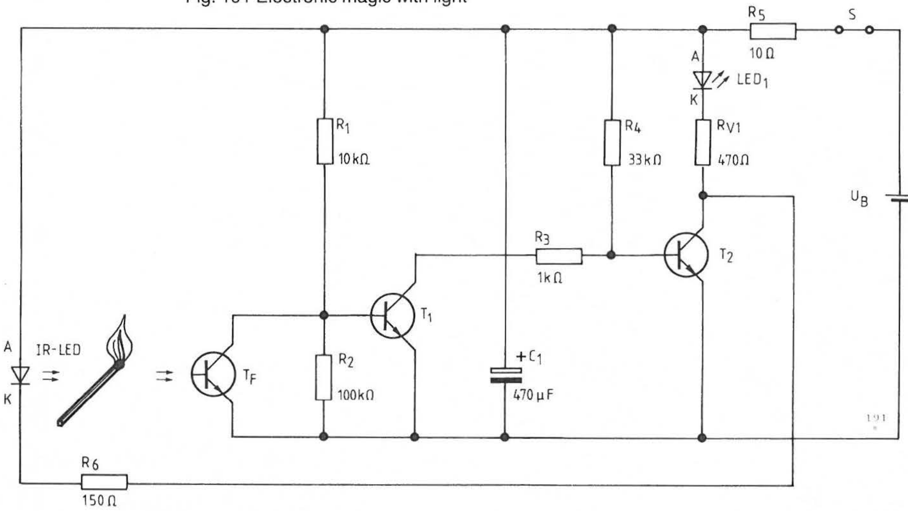

R6 150 Ω
K
A
IR-LED
A
K
LED1
R5 10 Ω
470µF
C1
R1 10 kΩ
R4 33 kΩ
Rv1 470 Ω
TF
E
C
1kΩ
R3
R2 100 kΩ
T1
T2
S
kosmos
P2
P1
190

Fig. 190 Construction of circuit 191

Fig. 191 Electronic magic with light

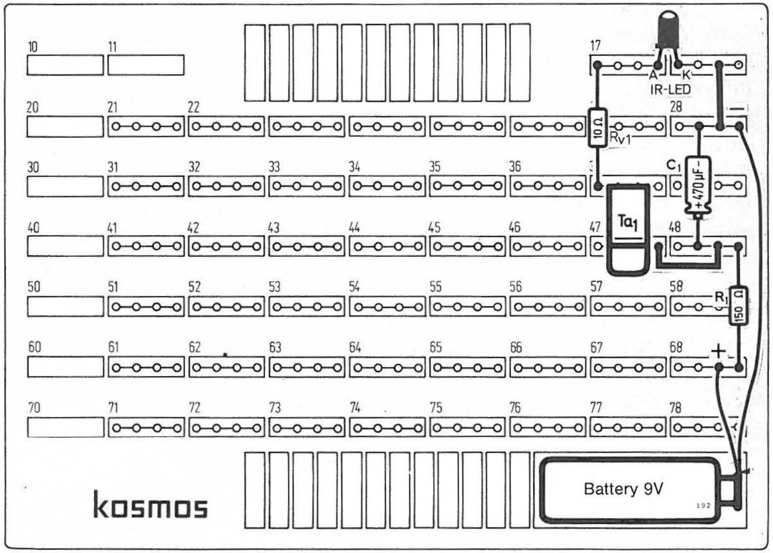

R5
10 Ω
S
A
LED1
K
R1
10kΩ
R4
33kΩ
RV1
470Ω
UB
+
9V
R3
1kΩ
T2
T1
A
IR-LED
K
TF
R2
100kΩ
+C1
470µF
R6
150Ω
191

or standard lamp or even to switch on the television set! Can the appliances be switched off again?

Of course, if you have a talent for acting you can make quite a show of it: Interrupt the infrared beam with an entreating gesture and – so long as no light from the lamp is falling on the phototransistor – the appliance will be turned of.

Quick thinkers will have seen through the “magic trick“ long ago; the phototransistor does not conduct until light (e.g. from the match) falls on it. When the phototransistor does not conduct then T1 is conducting and T2 nonconducting. This is the crux of the matter, T2 must provide the current for the IR diode, it must be made to conduct. And that is just what occurs when light falls on the phototransistor: Tf becomes conducting, T1 is nonconducting, T2 conducts and supplies current to the IR diode, which now happily delivers invisible light in the direction of the phototransistor and maintains its conducting state.

Fig. 192
Construction of circuit 193



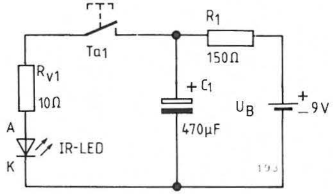


Fig. 193 Infrared transmitter

14.9 IR transmitter on a separate plug board

The transmitter and receiver need to be separated in space for the following circuits and experiments. The second plug board and an additional battery (9V power battery) are required. Attach the battery clip and insert the battery into the rectangular recess in the second plug board.

You can now build a simple infrared transmitter according to Fig. 192 (circuit diagram 193) which will be very useful for a variety of purposes.

14.10 Light barrier with alarm

The receiver is shown in construction diagram 194. The plug board with the transmitter is so arranged that the IR diode and the phototransistor are exactly opposite each other and a certain distance apart (the maximum possible distance must be found out by trial and error). An unpleasant whistling sound is produced as a warning as soon as the (invisible) light beam is broken. But

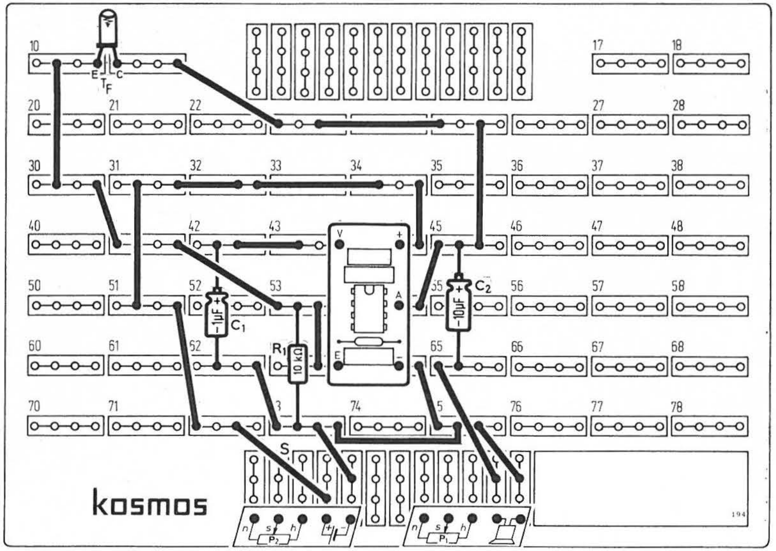
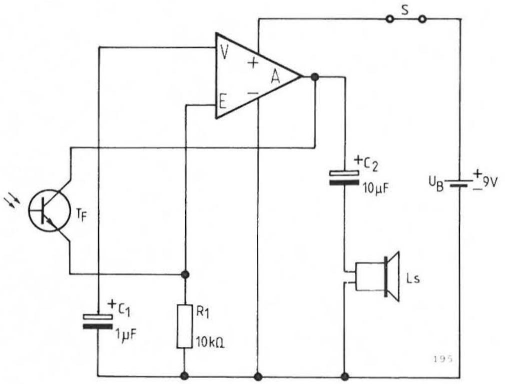


Fig. 194
Construction of circuit 195

Fig. 195 Light barrier with alarm



take care, the infrared transmitter “eats electricity“; continuous operation can only be recommended when the KOSMOS mains supply X is employed!

Experiment suggestion:

Hold a magnifying glass in front of the transmitter diode, to focus the beam. The distance that the infrared beam can bridge will now be considerably greater – under certain conditions it can – with a suitable magnifier – be more than a meter!

This experiment should only be carried out in a darkened room. A small tube of black card can be fitted onto the phototransistor to reduce the effect of the surrounding light.

14.11 Alarm without wires

Let us now turn the principle of the alarm just described on its head. A note will be produced if the light beam is **not** interrupted. Such an arrangement might be designated a universal remote-controlled alarm apparatus. It is constructed according to Fig. 196, Fig. 197 shows the corresponding circuit.

14.12 Infrared remote control

What can be remote-controlled? Now in order to study how it works, we will limit ourselves to LEDs, which can be switched on and off without any wire connection with the transmitter. Later the KOSMOS mains switch X (see end of book) can be included and you can use your remote control in practice with table lamps, cassette recorders, television sets, etc. The construction illustrated in Fig. 192 is employed again as transmitter. The receiver is illustrated in Fig. 198 (circuit diagram 199). It consists of a monoflop with amplifier module that is triggered when the phototransistor becomes conducting and a flip-flop that switches from one (stable) condition to the other every time it receives a negative impulse from the output of the amplifier module. The correct positioning of the transmitter diode in relation to the phototransistor must be found by trial and error. The series connection of LED1 and *R*v1 or LED2 and *R*v2 can be replaced by the KOSMOS mains switch X mentioned above.

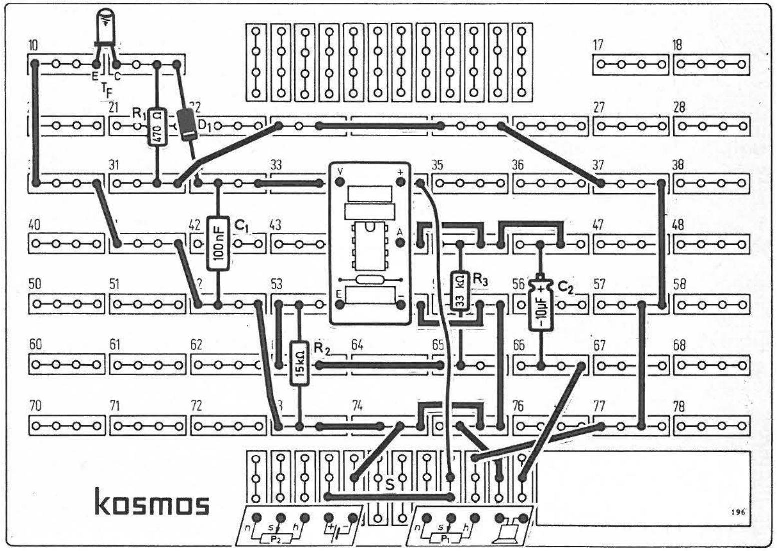

10
17
18
E
C
T_F
21
R1
470 Ω
22
D1
27
28
31
33
35
36
37
38
40
42
C1
100 nF
43
47
48
V
+
A
E
−
50
51
53
R3
33 kΩ
56
C2
10µF
57
58
60
61
62
R2
15kΩ
64
65
66
67
68
70
71
72
74
76
77
78
S
kosmos
n
s
h
P2
P1
196

Fig. 196 Construction of circuit 197

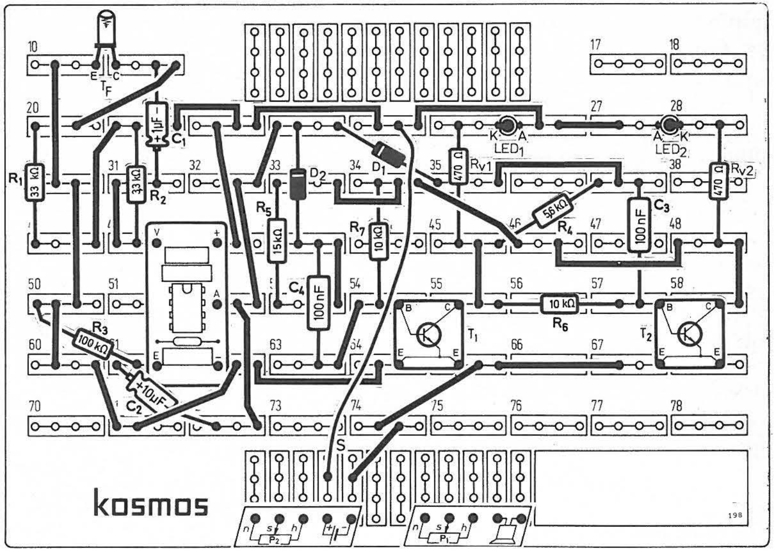

10
17
18
E
C
T_F
20
1µF
C1
27
28
K
A
LED1
LED2
R1
33 kΩ
31
R2
33 kΩ
32
33
D2
34
D1
35
470 Ω
Rv1
38
470 Ω
Rv2
R5
15kΩ
R7
10 kΩ
45
46
56 kΩ
R4
47
100 nF
C3
48
50
51
C4
100 nF
54
55
56
57
58
B
C
E
T1
10 kΩ
R6
T2
60
R3
100 kΩ
C2
10µF
63
66
67
70
73
74
75
76
77
78
S
kosmos
n
s
h
P2
P1
198

Fig. 198 Construction of circuit 199

Fig. 199 Infrared remote control

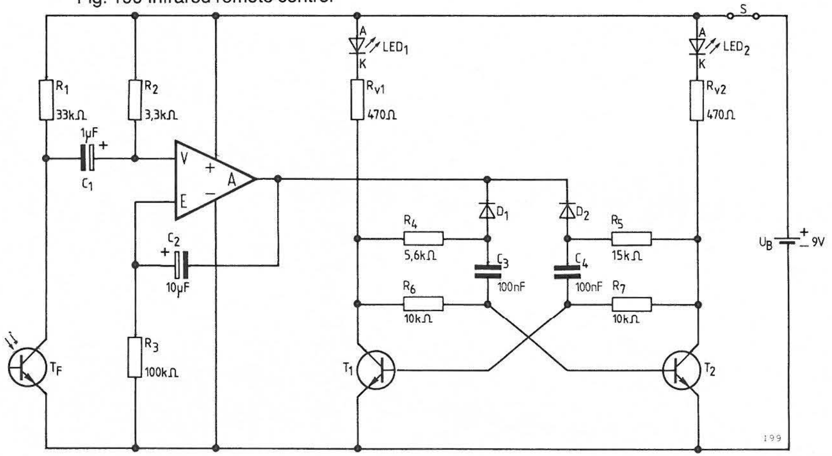
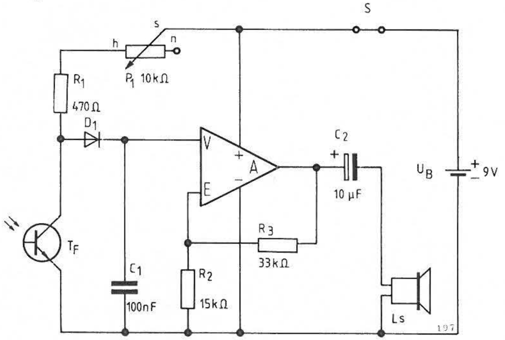

S
A
LED1
K
Rv1
470Ω
A
LED2
K
Rv2
470Ω
R1
33kΩ
R2
3,3kΩ
1µF
+
C1
V
+
A
E
−
C2
+
10µF
R3
100kΩ
T_F
R4
5,6kΩ
D1
D2
R5
15kΩ
C3
100nF
C4
100nF
R6
10kΩ
R7
10kΩ
T1
T2
U_B
+
9V
199

Fig. 197 Infrared alarm without wires


s
h
n
P1 10kΩ
S
R1
470 Ω
D1
V
+
A
E
−
C2
+
10 µF
U_B
+
9V
T_F
C1
100nF
R2
15kΩ
R3
33kΩ
Ls
197

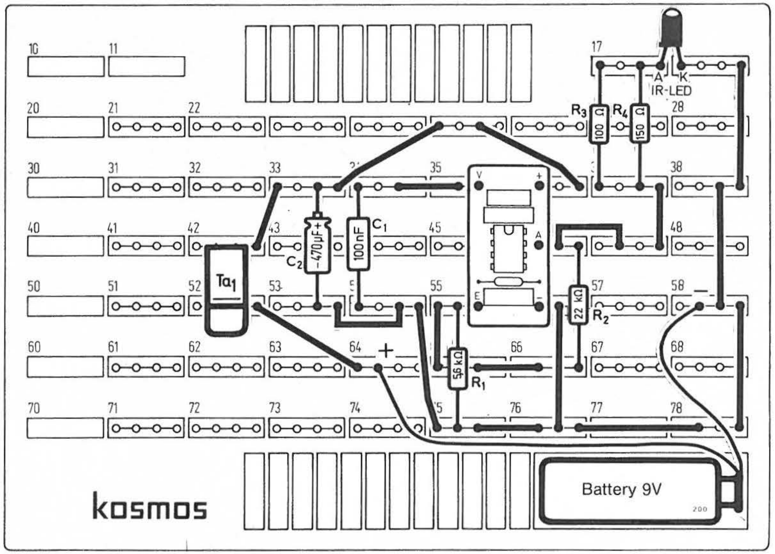
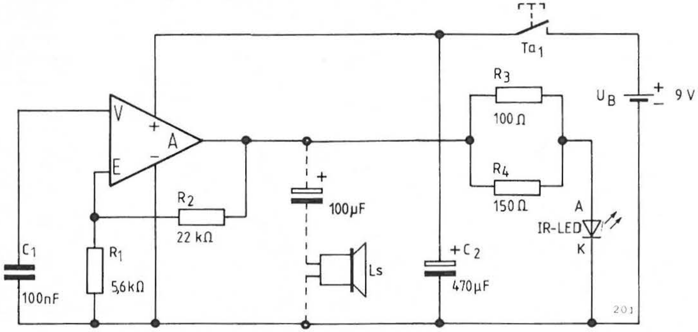

IR-LED
A
K
R3
100 Ω
R4
150 Ω
C1
100nF
C2
470µF
Ta1
22 kΩ
R2
5,6 kΩ
R1
V
A
E
Battery 9V
kosmos

Fig. 200 Construction of circuit 201

Fig. 201 Infrared impulse-operated transmitter


Ta1
R3
100 Ω
R4
150 Ω
UB
+
9 V
V
A
E
R2
22 kΩ
100µF
A
IR-LED
K
C1
100nF
R1
5,6kΩ
Ls
C2
470µF
201

14.13 Flickering light

A light beam (in our case an infrared light beam) can also be employed to transmit information. The simplest method of doing this is to switch the transmitter diode periodically on and off very rapidly, e.g. by contolling it with a note generator. On the receiver side the chopped light signal is then turned back into an electrical signal, which can be fed to a loudspeaker after it has been amplified. This means that a note can be transmitted over a distance.

The necessary transmitter circuit is given in Fig. 201. The transmitter is once again assembled on a separate plug board (Fig. 200). The amplifier module is wired as a note generator, the IR diode receives its current from the amplifier output. In order to test first of all whether the transmitter circuit operates connect the loudspeaker to the amplifier output via a 100µF capacitor and two long wires (shown hatched on the circuit diagram); when the contact maker is pressed a loud note should be produced. The loudspeaker can then be switched off (by removing the long wires).

14.14 Transmitting morse signals without wires

The circuit for the reception of notes without wires is shown in Fig. 203. The voltage changes produced at the collector of the phototransistor by

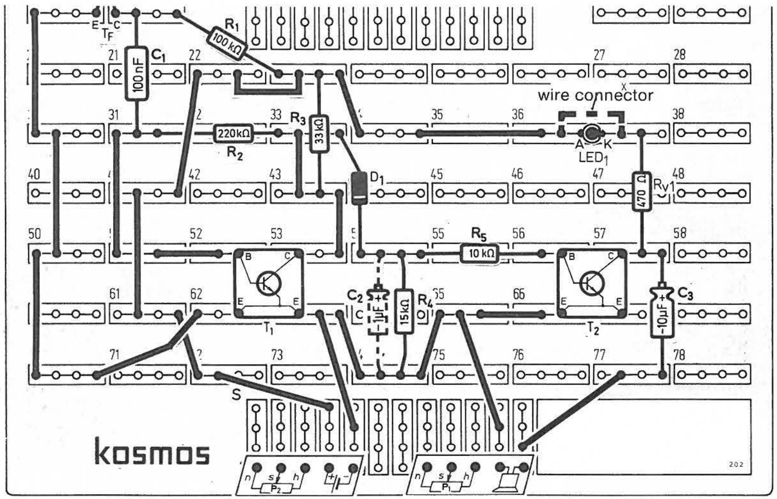

T_F
E C
R1
100kΩ
C1
100nF
21
22
27
28
wire connector
x
31
33
R3
33kΩ
220kΩ
R2
35
36
38
LED1
A K
40
42
43
D1
45
46
47
470 Ω
Rv1
48
50
52
53
55
R5
10kΩ
56
57
58
B C
E E
T1
T2
61
62
C2
1µF
15kΩ
R4
65
66
C3
10µF
71
73
75
76
77
78
S
kosmos
P2
P1
n s h
202

Fig. 202
Construction of circuit 203

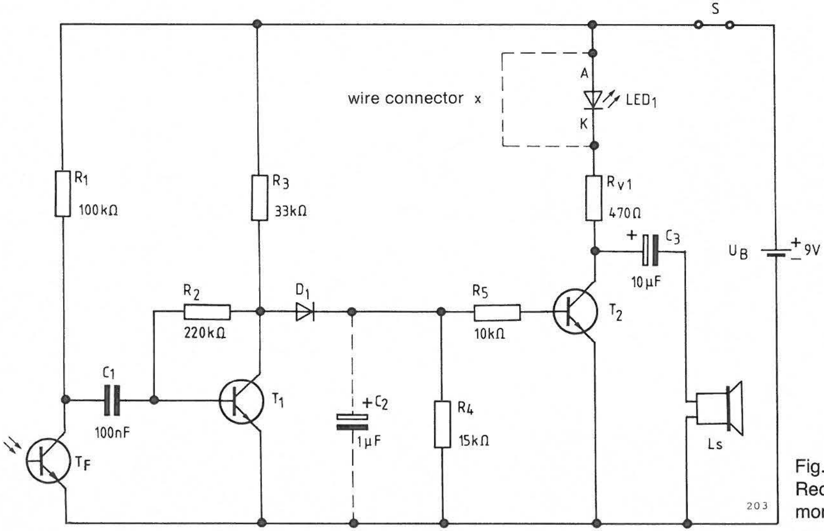

S
wire connector x
A
LED1
K
R1
100kΩ
R3
33kΩ
Rv1
470Ω
+
C3
10µF
U_B
+ 9V
R2
220kΩ
D1
R5
10kΩ
T2
C1
100nF
T1
+C2
1µF
R4
15kΩ
T_F
Ls
203

Fig. 203
Receiver for infrared morse signals

the "flickering light" are transmitted via capacitor *C*1 as impulses to the base of T1. The diode will be important for the impulsed light barrier in the next section; you do not need to bother further with it here. The loudspeaker is connected to the collector of the last transistor via a capacitor; a great deal of sound is not to be expected from this type of "final stage". Bring the layout into operation by first bringing the transmitting diode right up to the phototransistor and pressing the contact maker. You are sure to hear a distinct note. Now separate the transmitter from the receiver in stages and find out the maximum possible distance between the two (do not forget to press the contact maker!).

Experiment suggestion:

In order to reduce the effect of surrounding light a small tube of black card can be fitted over the phototransistor. This measure sometimes improves reception.

14.15 Energy-saving impulsed light barrier

We also want to go along with the worldwide trend towards energy conservation and we are going to use the knowledge acquired in the last section to build a light barrier employing pulsed light. It is obvious that the current consumption falls rapidly on the transmitter side, if the light beam is constantly switched on and off. Furthermore there is another theoretical advantage, but we are not going to exploit it. The infrared diode can accommodate an enormously large impulse of current for a short time, if it is given time to recover afterwards, i.e. to cool down, in order to avoid the danger of overheating. In industrial practice currents of several amperes are passed which only last for a few microseconds, these are followed by "pauses for recovery" in the millisecond range. The advantage is obvious; a high light intensity is produced for a very short time, so that the transmission range is increased.

Now rebuild the transmission and reception circuits from the last section. Remove the contact maker from the transmitter plug board and replace it with a wire connector (continuous note). In the case of the receiver add the capacitor *C*2 which is hatched in Fig. 202 and remove the loudspeaker capacitor *C*3 and fit a LED instead of the wire connector x.

If the transmitter is now aimed at the receiver then the LED lights up. *C*2 prevents it from flickering; it is charged by the pulsating voltage, diode D1 prevents rapid discharge. Interruption of the light beam (light barrier) leads to the extinction of the LED after a slight pause.

Suggestion for experiment:

Insert a normal LED instead of the IR diode. The layout naturally functions with this too; however the transmission distance is very limited because the phototransistor is most sensitive in the IR range.

14.16 A special sort of tele game: a dimmer without wires

You know from Section 14.12 how to switch on lamps, appliances and the like without wires. Now you are going to go one step further and try to dim a LED slowly from a distance (construction of the receiver Fig. 206, circuit diagram 207).

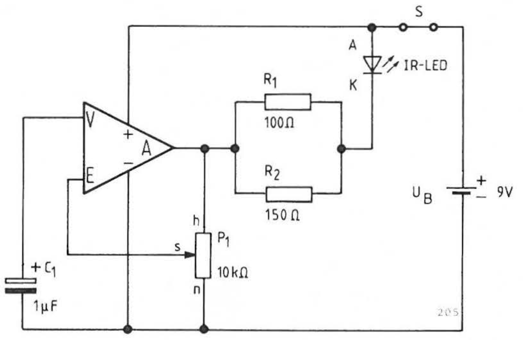
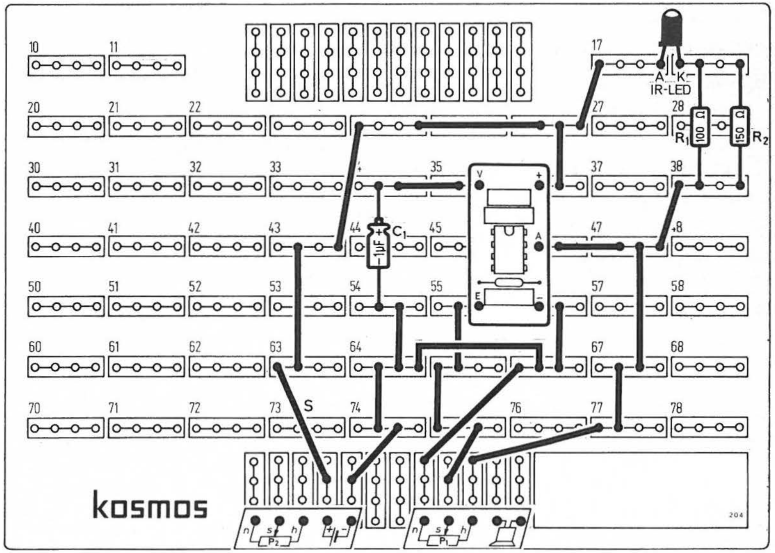

S
A
K
IR-LED
R1
100Ω
R2
150Ω
V
+
A
−
E
h
s
P1
10kΩ
n
+C1
1μF
U_B
+
9V
205

Fig. 205 Transmitter of dimmer without wires

Fig. 204 Construction of circuit 205


10
11
17
A
K
IR-LED
20
21
22
27
28
R1
100Ω
150Ω
R2
30
31
32
33
35
V
+
37
38
40
41
42
43
44
C1
1μF
45
A
47
48
50
51
52
53
54
55
E
57
58
60
61
62
63
64
67
68
70
71
72
73
S
74
76
77
78
kosmos
n
s
h
P2
P1
204

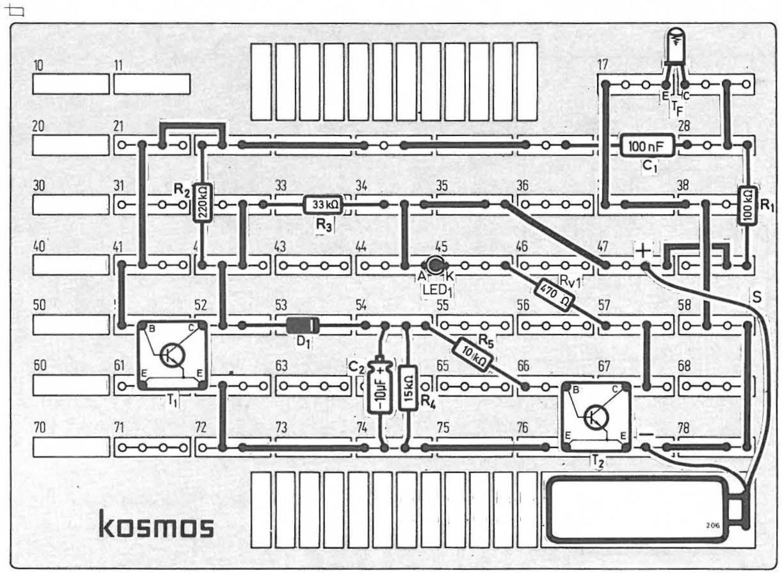

kosmos
R2
220kΩ
33kΩ
R3
100 nF
C1
100kΩ
R1
LED1
A
K
Rv1
470 Ω
D1
R5
10kΩ
C2
10µF
15kΩ
R4
T1
T2
TF
E
C
B
S
+
–
206

Fig. 206
Construction of circuit 207

Here it is necessary to know that capacitor *C2* has to be allowed a little time between two impulses, in order to discharge, i.e. the "in" impulse must be kept short and the "out" impulse must be made long. Thus the time-averaged charge potential of the capacitor drops and the LED becomes less bright.

This trick of adjusting the ratio of time in and time out (this is known as the **duty factor**) is carried out at the transmitter with potentiometer P1 (circuit 205, construction 204). If P1 is turned very carefully, it is possible to control the brightness of the LED precisely. However, care is needed because the adjustment range of the potentiometer is not very large.

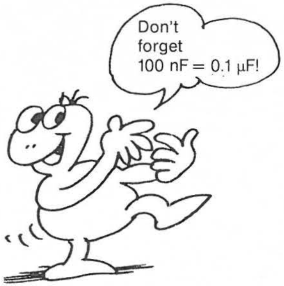
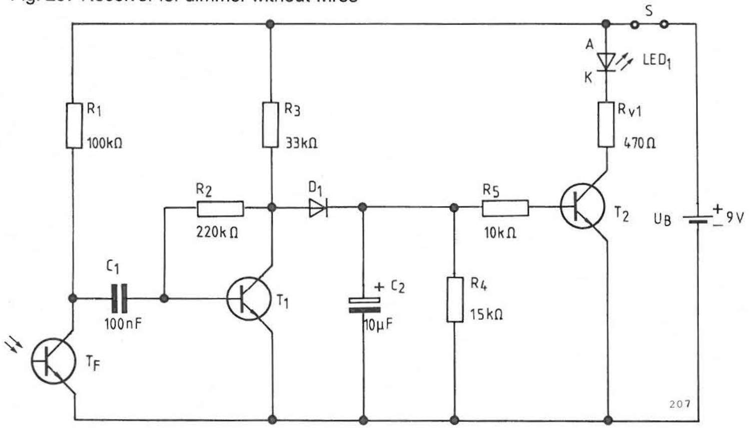
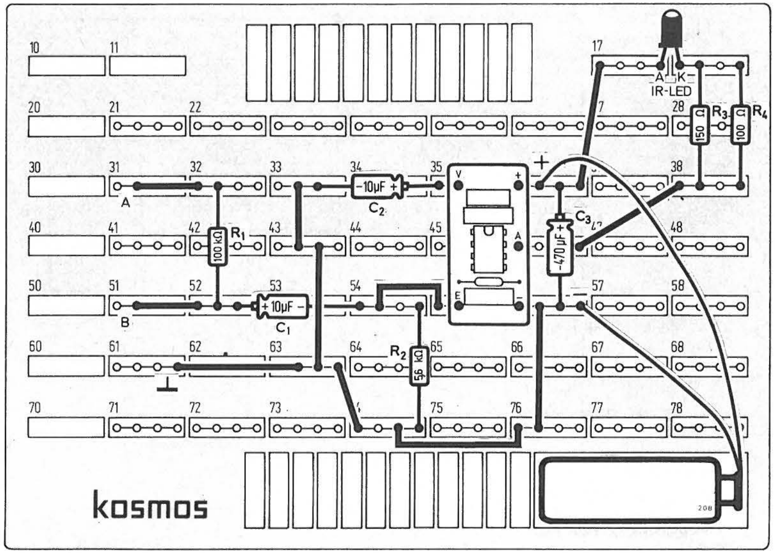

Don't forget 100 nF = 0.1 µF!

Fig. 207 Receiver for dimmer without wires


S
A
K
LED1
R1
100kΩ
R3
33kΩ
Rv1
470Ω
R2
220kΩ
D1
R5
10kΩ
T2
UB
+
9V
C1
100nF
T1
+ C2
10µF
R4
15kΩ
TF
207

14.17 Light transports music

If it is possible to modulate radio waves it ought to be child's play to transmit information "piggyback" on light waves; after all they are both forms of electromagnetic radiation and only differ in their frequency. And it does actually work and the day is not far off when "cordless telephones" using modulated infrared radiation will be taken for granted – perhaps even while this book is being printed.


10
11
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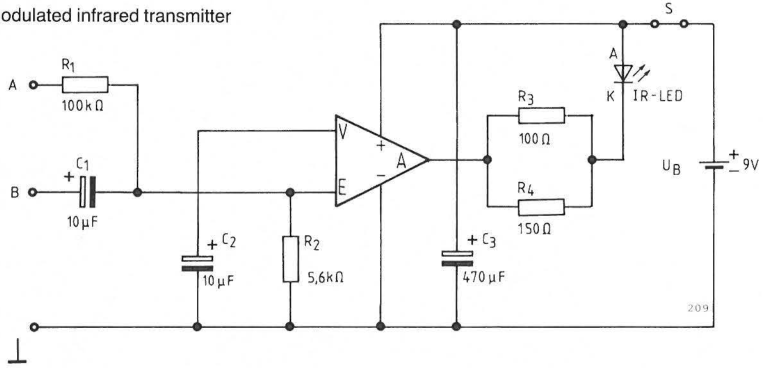
21
22
7
28
30
31
32
33
34
35
38
A
40
41
42
43
44
45
48
50
51
52
53
54
57
58
B
60
61
62
63
64
65
66
67
68
70
71
72
73
75
76
77
78
17
A K
IR-LED
R₃
R₄
150 Ω
100 Ω
R₁
100 kΩ
10µF
C₁
10µF
C₂
C₃
470 µF
R₂
5,6 kΩ
V
E
+
−
kosmos
208

Fig. 208 Construction of circuit 209

Figure 209 is the circuit diagram for a transmitter of amplitude- modulated infrared rays. If a cassette recorder, crystal system record player or a household radio is connected to input A or a dynamic microphone to input B, then the transmission beam will alter slightly in intensity in time with the speech or music (construction of the transmitter Fig. 208).

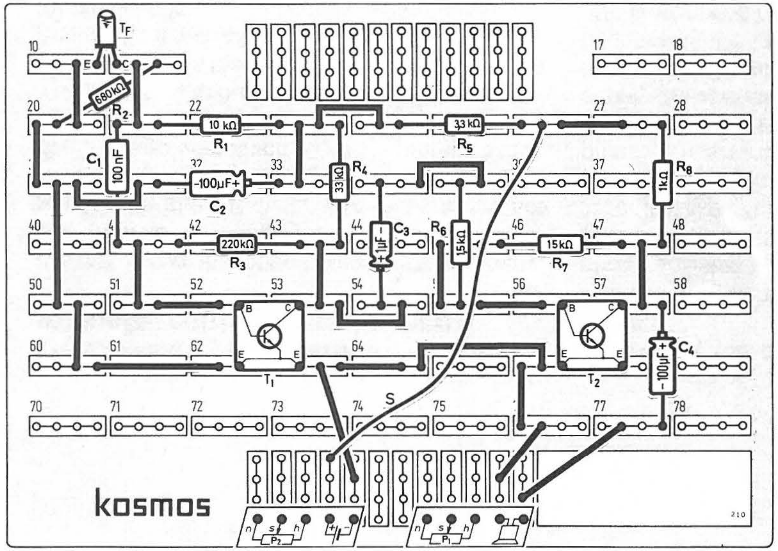
The accompanying receiver according to Fig. 211 (construction 210) does not contain any great secrets. It consists of the receiver transistor Tf and two amplifier steps with T1 and T2. Here again the simple final stage means that high loudspeaker output cannot be expected.

Fig. 209 AF-modulated infrared transmitter


S
A
K
IR-LED
R1
100kΩ
A
B
C1
10µF
C2
10µF
R2
5,6kΩ
V
E
A
+
−
C3
470µF
R3
100Ω
R4
150Ω
U_B
+ 9V
209

14.18 Optoisolator – a modern electronic component

A unit containing a light transmitter (LED or IR diode) focussed on a light receiver (phototransistor, photodiode), is known as an optoisolator. These are employed in practice when it is necessary to separate two circuits with different voltage supplies completely from each other (potential separation). They are sold as complete units (transmitter and receiver in one unit) and are able to separate circuits from one another with potential differences of up to 1000V.


T_F
E
C
680kΩ
R₂
10 kΩ
R₁
C₁
100nF
-100µF+
C₂
33kΩ
R₄
3,3 kΩ
R₅
1kΩ
R₈
220kΩ
R₃
1µF
C₃
R₆
15kΩ
R₇
B
C
E
T₁
T₂
100µF
C₄
S
kosmos
n s h
P₂
P₁
10
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77
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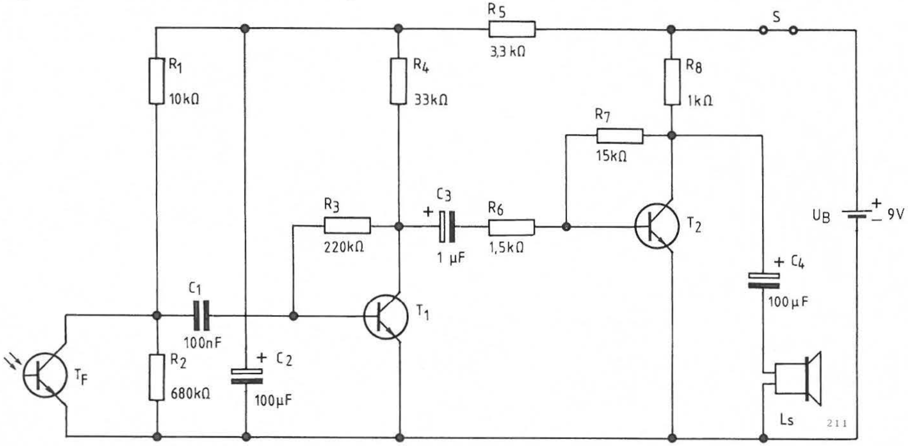
210

Fig. 210
Construction of circuit 211

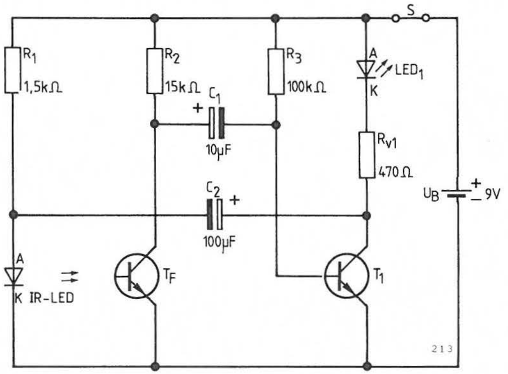
Fig. 211 Receiver for modulated infrared light

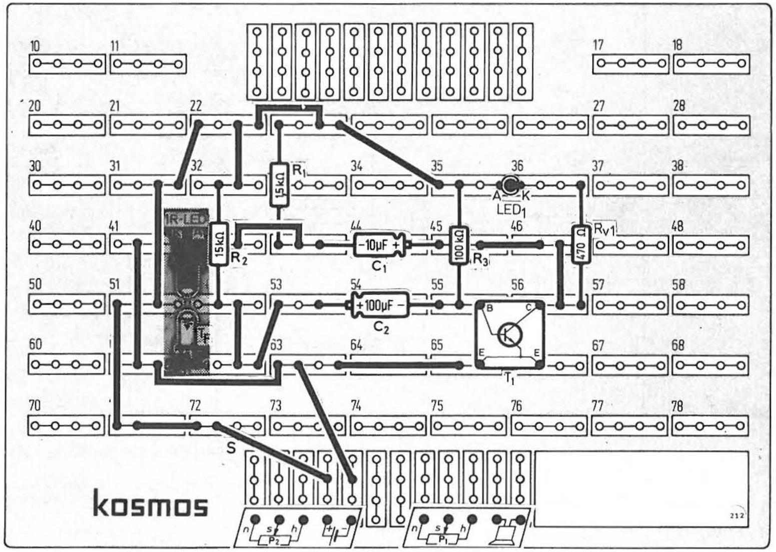

R5
3,3 kΩ
S
R1
10kΩ
R4
33kΩ
R8
1kΩ
R7
15kΩ
R3
220kΩ
C3
1 µF
R6
1,5kΩ
T2
UB
9V
C4
100µF
C1
100nF
R2
680kΩ
C2
100µF
T1
TF
Ls
211

14.19 Optically coupled in swing

1000V are not for us and anyway we do not have the problem of separating two circuits from one another. However, you can study the principle of the optoisolator. You can do this very well with an astable multivibrator, which consists – along with the necessary capacitors and resistors – of a normal transistor, a phototransistor and an IR diode (circuit diagram 213). The "optoisolator" is shaded gray in the construction diagram 212.
A comparison of the circuit with that in Fig. 90 shows that there is, in fact, no difference from a normal astable multivibrator; it is just that the base connection to the left-hand transistor is made by the opto route.

Fig. 213 Astable multivibrator with optoisolator


S
R1
1,5kΩ
R2
15kΩ
C1
10µF
R3
100kΩ
A
LED1
K
RV1
470Ω
UB
9V
C2
100µF
A
K IR-LED
TF
T1
213


10
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53
54
55
56
57
58
60
63
64
65
67
68
70
72
73
74
75
76
77
78
R1
15kΩ
R2
15kΩ
IR-LED
TF
-10µF +
C1
100kΩ
R3
A
K
LED1
Rv1
470Ω
+100µF -
C2
B
C
E
E
T1
S
P2
P1
kosmos
212

Fig. 212
Construction of circuit 213

14.20 Waking up to music – a light intensity-controlled radio alarm

It is well-known that nobody likes getting up early. But when needs must, you, as a student of electronics, can at least make sure that you are not rudely awakened by a primitive alarm clock; you can manage something more elegant than that. Let us try out one possibility.

You are going to build a radio receiver, that switches itself on as the morning dawns, that is when enough light is available to make a phototransistor conducting. The AM circuit, whose construction is in Fig. 133, can be rebuilt for the purpose in a trice.

Remove wire connector x and replace it by the phototransistor.

(Make sure that its shorter connection is inserted in contact clip 27). The circuit is now supplied with current via the phototransistor. If light is not falling on it then it is nonconducting and the radio keeps quiet, because the phototransistor refuses to supply the operating current. As the cock begins to crow the phototransistor also becomes active, because light is falling on it; the radio is supplied with current and begins to work.

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electronic X 3500/X 4000

Franckh'sche Verlagshandlung
Stuttgart

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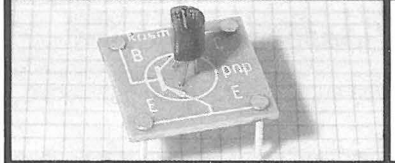
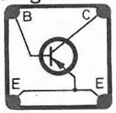
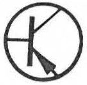
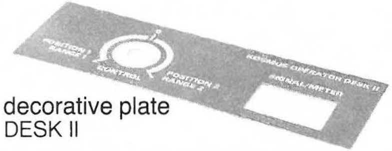
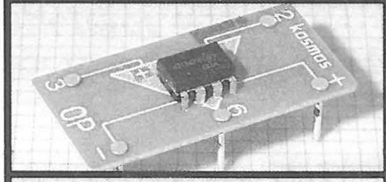
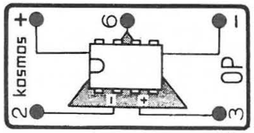
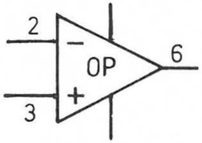
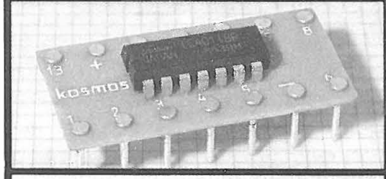
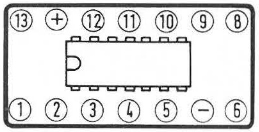
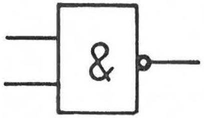
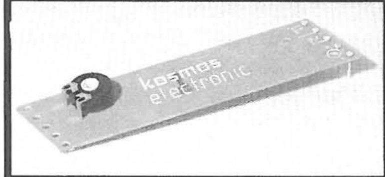
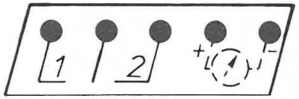
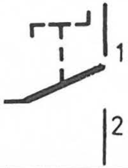
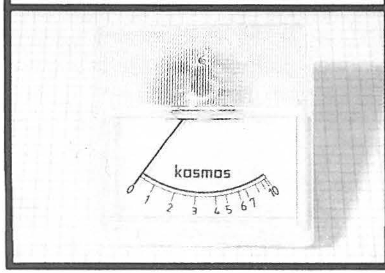
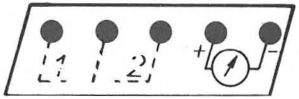
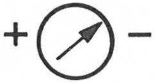
The new components for electronic X 4000

	construction diagram  pnp transistor circuit diagram 	 decorative plate DESK II
	  operational amplifier	
	  Quad NAND gate	
	  range-switch strip	
	  meter 100 μA 1200 Ω	

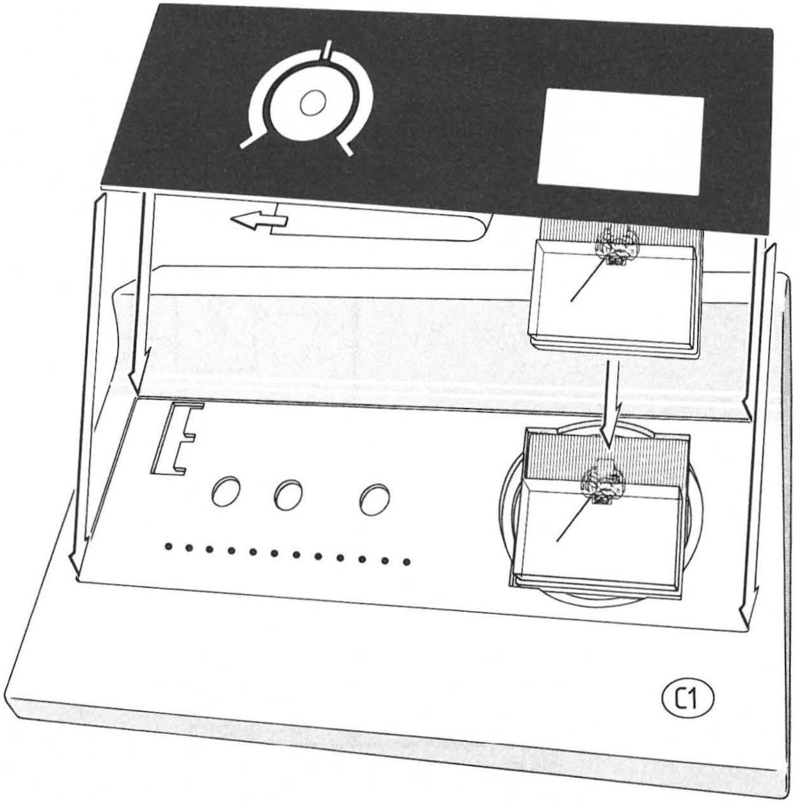
15. From "specialist" to "professional"

Anyone who has gone through all the experiments up to now can be called a specialist without any fear of exaggeration.
We are now going to go on and conquer further fields of electronics. The main topics will be operational amplifiers, measurement and digital electronics. We will continue to try to get down to the basics, without getting too theoretical; sometimes it will be useful to bring in an equation and the odd calculation will have to be carried out.
The first thing to do, as in the previous section, is to introduce the new components. Now you will see how easily the second operator desk is assembled with its meter and range switch.

16. Assembly of the second operator desk

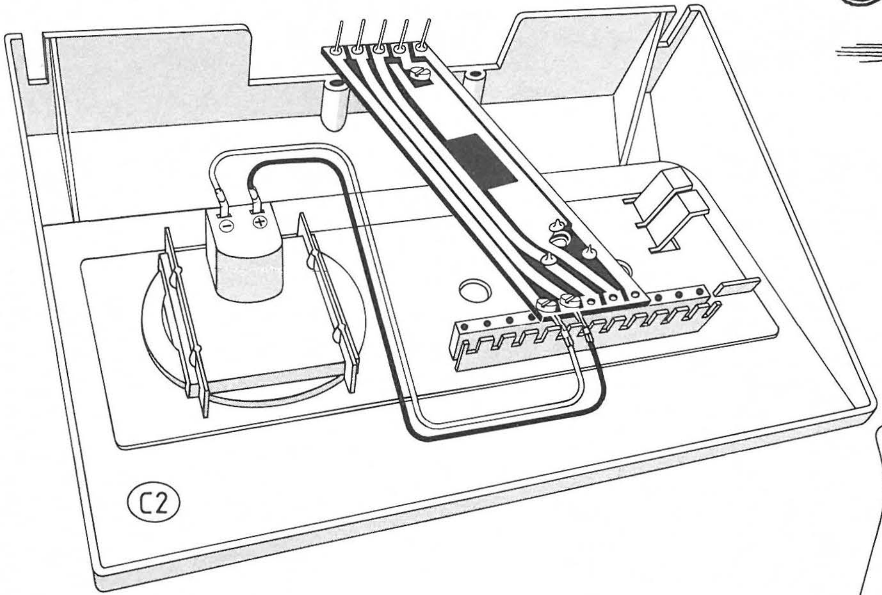
The following are required for the assembly:
the operator desk,
the decorative plate DESK II,
the meter,
the range switch strip,
the large adjustment knob
and the three small screws.

You will also require a small screwdriver, a kitchen cloth and some household cleanser. First wash the top of the operator desk, particularly the depression into which the decorative plate will be fitted, and then rub it thoroughly dry. Insert the meter into the space provided as shown in Fig. C1. You can also see in this sketch how the decorative plate is stuck on, first remove the protective backing.



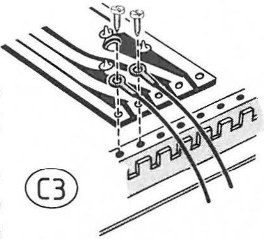
C1

Press the plate down firmly; any air bubbles that get trapped can be pressed towards the edge. Now turn the desk upside down and insert the range switch strip from below.



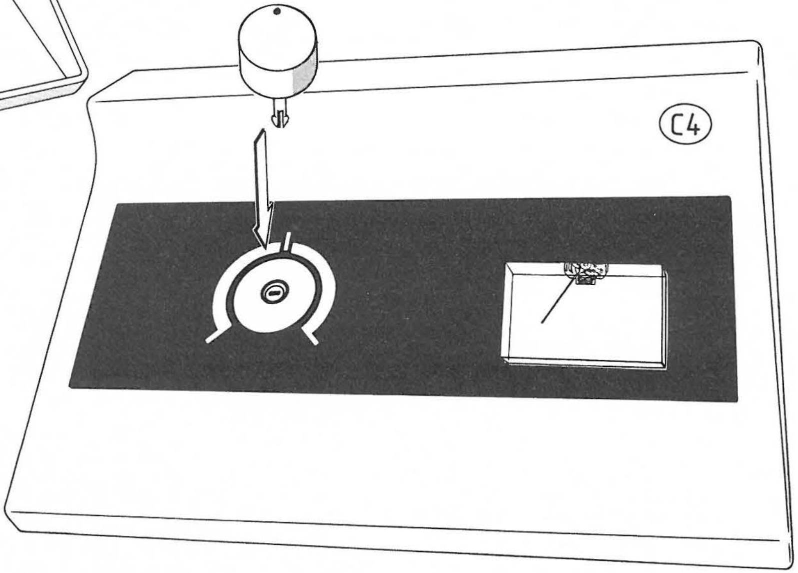
C2

This is fitted so that there are 3 holes free to the right and 4 holes free to the left on the mounting (see Fig. C2).
Attach the red lead of the meter to positive (+) and the black lead to negative (−) on the range switch strip. The eyelets of the leads must be screwed firmly onto the conductor tracks (see Fig. C3).



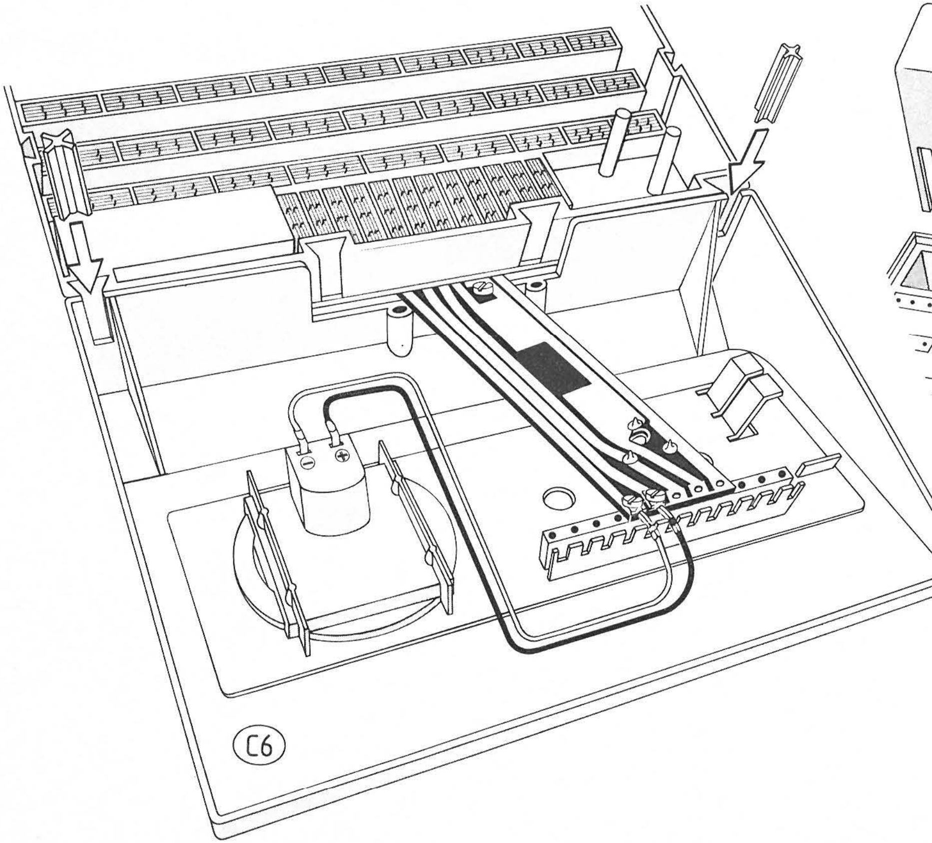
C3

Finally attach the range switch strip to the edge of the operator desk by means of the third screw. You can now turn the operator desk the right way up. Use the small screwdriver to turn the socket for the adjustment knob so that it is horizontal. The large adjustment knob can then be pushed on gently as shown in Fig. C4. When doing this make sure that the marking point is facing the zero (0) on the decorative plate.

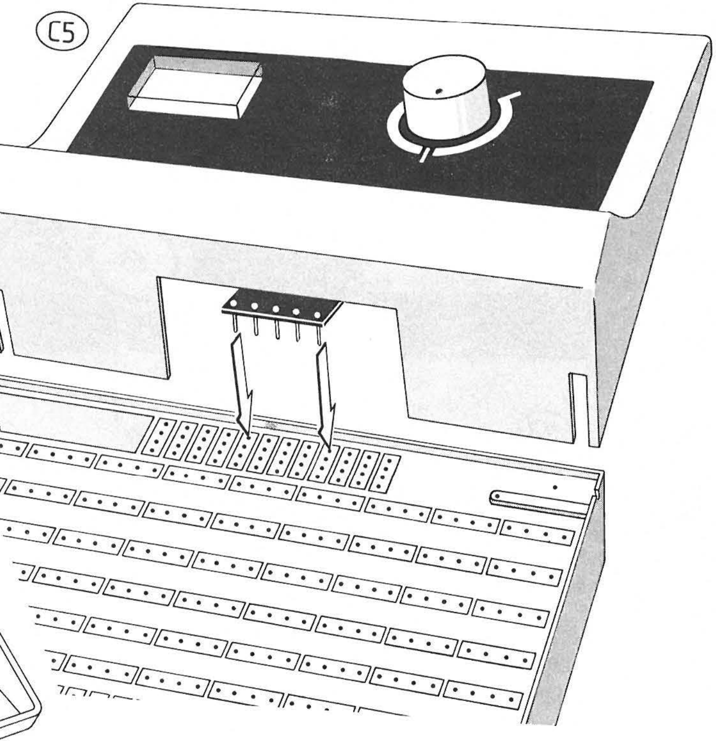


C4

The second operator desk is now ready. Figs. C5 and C6 show how it is attached to the plug board. Make sure that the contact pins are fitted into the appropriate contact clips and then fit the two connecting rods in **from below**.

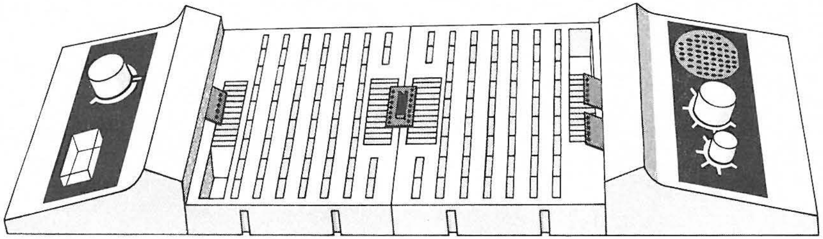


C6



C5

Then, if you have not already done so, you should fit the remaining contact clips to the plug board. It is possible to connect the two operator desks and plug boards together in several ways. Two arrangements are included on the box of the electronic X 3000 and X 4000 kits. The two plug boards are attached together by fitting the connecting rods, as is illustrated in Fig. C8, always do this **from below**. In Section 21 the boards are



C7

assembled next to each other as in Fig C7. The digital module is then attached "across" both boards; the exact arrangement is shown in the appropriate constructional diagrams from Section 21 on.

In what follows the various circuits and appliances will employ the switch marked "control" on the "operator desk II" as a range switch. Figure 214 shows a simple changeover layout for testing. With the switch in position 1 ("RANGE 1") the left LED is illuminated; with the switch in position 2 ("RANGE 2") the right LED is in the circuit. As you turn the range knob from one stop to the other you will feel a slight resistance when the knob points to the middle ("0"). In this position the central connection of the switch is not connected to either of the two outer connections. The control switch can be employed without any problems as an on/off switch in place of the wire connector S. It is only necessary to set up the correct connections with two long wires. However, the representation of the on/off function has been omitted for the sake of clarity.

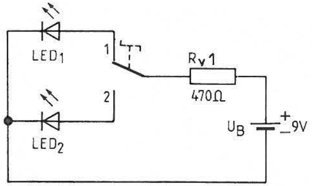
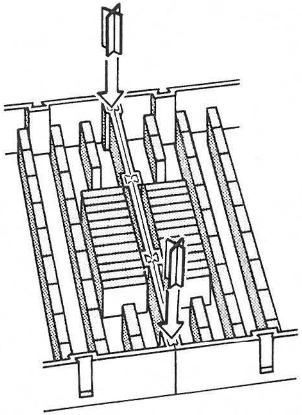
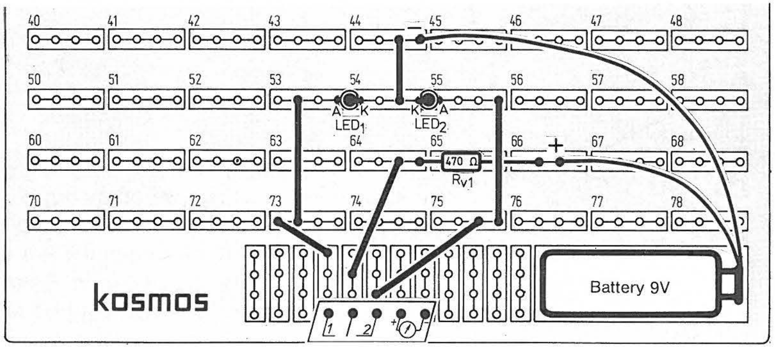

LED1
LED2
1
2
Rv1
470Ω
UB
+
9V

Fig. 214 Applications of the control switch



C8


40
41
42
43
44
45
46
47
48
50
51
52
53
54
55
56
57
58
A K
LED1
K A
LED2
60
61
62
63
64
65
66
67
68
470 Ω
Rv1
+
70
71
72
73
74
75
76
77
78
kosmos
1
2
Battery 9V

17. Operational amplifier techniques

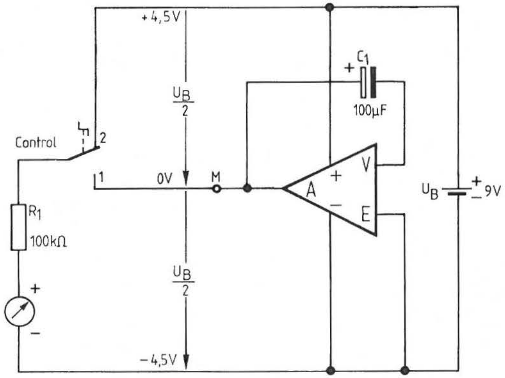
At first you are sure to be puzzled by the name "operational amplifier". What sort of operations are meant?

Before the present-day digital computer conquered the world, calculating machines were built that could carry out mathematical operations by employing high quality amplifiers; they were known as analogue computers (we will return to the difference between "digital" and "analogue" in Section 21). Analogue computers have not become completely extinct but they have been largely replaced by digital computers. What does remain, however, is the operational amplifier, which is an important component for the electronics designer because it has such a wide range of applications.

Most operational amplifiers require two supply voltages in order to operate properly and since we do not wish to employ two batteries, we will produce a double supply by means of an electronic trick.

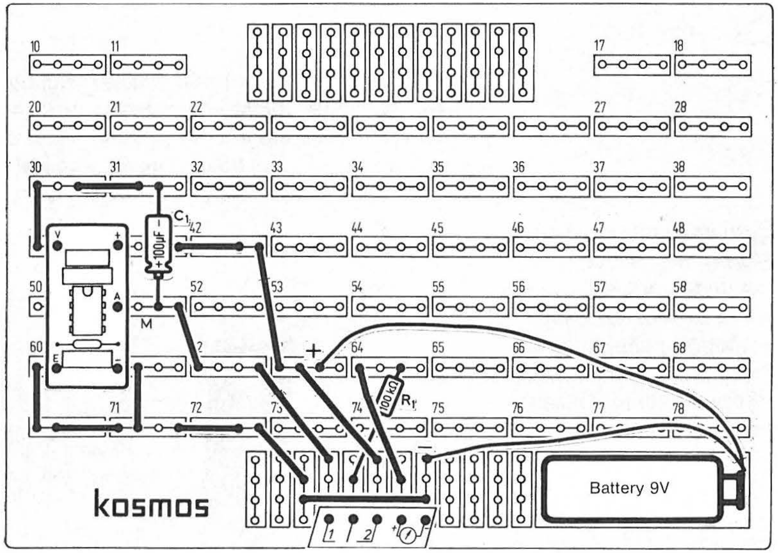
17.1 Versatile amplifier module – divides voltages into two halves

Glance quickly again at Table 5 – if the input E of the amplifier module is connected to the negative pole of the battery (and input V is unconnected or connected by means of an electrolytic capacitor to the output to avoid stray voltages), then ca. half the battery voltage appears at the output. That can be checked immediately by means of the meter. Figure 215 shows the constructions and Fig. 216 the corresponding circuit diagram. Depending on the position of the range switch the meter scale reads either 4.5 or 9.



+4,5V
$\frac{U_B}{2}$
C_1
+
100µF
Control
2
1
0V
M
A
+
V
−
E
U_B
+
9V
R_1
100kΩ
+
−
$\frac{U_B}{2}$
−4,5V

Fig. 216 The amplifier module produces +4.5V and −4.5V



10
11
17
18
20
21
22
27
28
30
31
32
33
34
35
36
37
38
C_1
100µF
42
43
44
45
46
47
48
V
+
A
E
M
50
52
53
54
55
56
57
58
60
64
65
66
67
68
+
71
72
73
74
75
76
77
78
100kΩ
R_1
−
Battery 9V
kosmos
1
2

Fig. 215 Construction of circuit 216

17.2 Ground in the middle

An agreement will now be made concerning working with the operational amplifier, which – if you remember once again the arguments of Section 1.3 – will come as no surprise to you. The connection to the "half voltage" (labelled with M in Fig. 216) will be defined as ground, so that with this new basis for regarding voltages and measurements a voltage supply of ca. +4.5V and −4.5V (with respect to ground) is available. In order to avoid unnecessary complications in the circuit diagrams we will also agree to label all parts of the circuit that are connected to ground with the ground symbol illustrated in Fig. 217. If it sometimes appears that some parts of the circuit are "hanging in the air" you will know (and you can follow it on the basis of the constructional diagram) that all points lebelled ground are actually connected to one another.

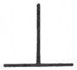


Fig. 217 Circuit diagram symbol for ground

17.3 Measurement means comparison

You were taught that in school in physics; formerly a length of one meter that was to be measured was "compared" with the international standard meter at Sevres near Paris. That is the scales of all meter rules and measuring tapes were referred to this standard meter. Even though the standard meter is only of historical interest nowadays because the reference now consists of a sophisticated method employing a certain number of wavelengths of a light beam, all measurements are still made in practice by comparsion. Because comparsion evidently plays such a role, we will now study the behavior of the operational amplifier in a comparator circuit.

17.4 Small causes, large effects – the comparator

What does the operational amplifier do with the two voltages, which are delivered to it at pins 2 and 3?
It acts as a comparator. It is able to react to tiny voltage differences between pins 2 and 3 (we call them inputs) in a violent manner by producing comparatively high positive or negative voltages at the output (pin 6).

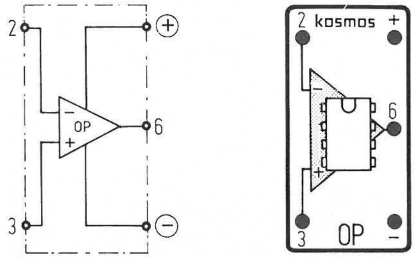


Fig. 217a The KOSMOS OP AMP module

Instead of taking a look inside the operational amplifier let us consider a comparator model. A glass plate stands on two adjustable legs. There is a heavy steel ball lying on the plate. There are movable metal plates to the left and right of it which are connected by means of a link so that they always move together (Fig. 218).

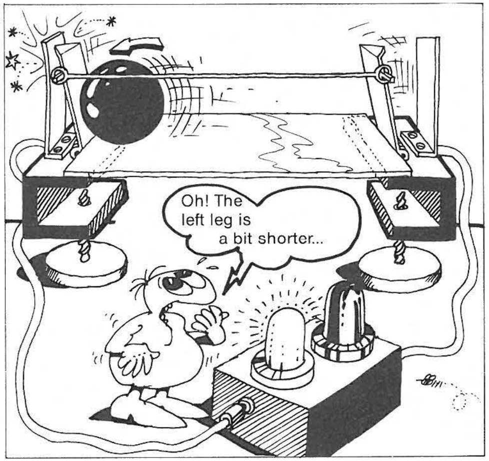

Oh! The left leg is a bit shorter...

Fig. 218 Comparator model; which leg is shorter?
The ball cannot take up any intermediate position.

In spite of every effort it will not be possible to adjust the two legs so that they are precisely equal. The glass plate will always be slightly tilted. Since there is practically no friction between the ball and the glass plate, the ball will roll to one side or the other. So the ball is able to compare the height of one leg with that of the other. It

reacts to the height difference on the all-or-nothing principle. Even the slightest difference in height has the effect of making the ball roll to one side or the other, it never remains in the middle. It indicates thereby which leg is higher by pressing against the left or the right-hand contact.
You now have a model of the working of the operational amplifier as a comparator. Now let us turn to the operational amplifier itself.

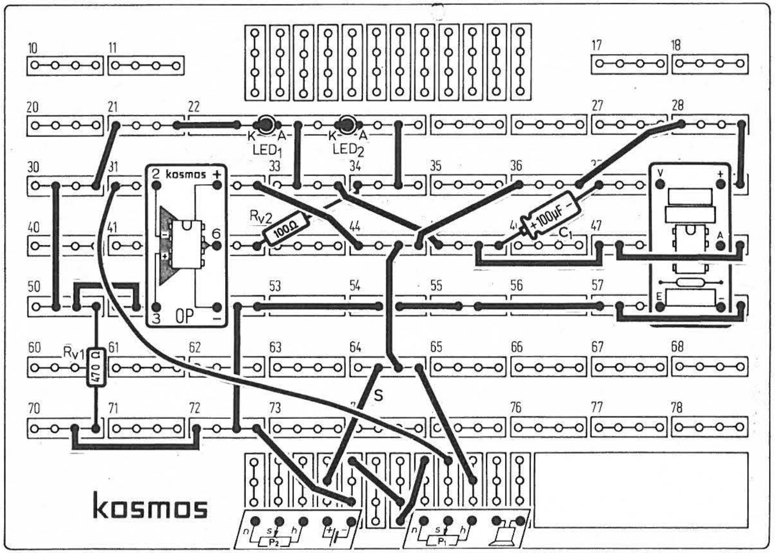
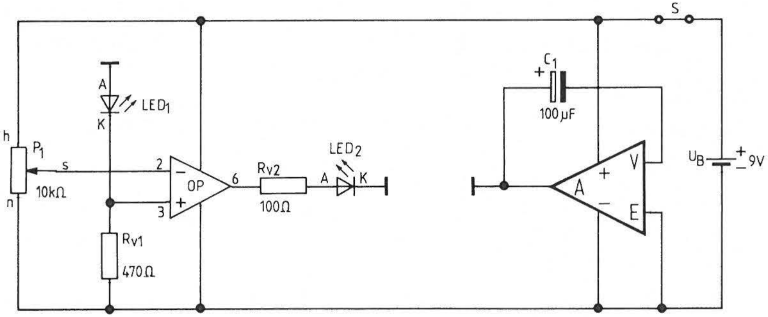

10
11
17
18
20
21
22
27
28
K
A
LED1
LED2
30
31
33
34
35
36
2 kosmos +
6
3 OP −
Rv2
100Ω
44
+100µF −
C1
47
40
41
50
53
54
55
56
57
V
A
E
60
Rv1
470Ω
61
62
63
64
65
66
67
68
S
70
71
72
73
76
77
78
kosmos
n
s
h
P2
P1

Fig. 219 Construction of circuit 220

17.5 All or nothing – that is the question here

The comparator is constructed according to Fig. 219. You can see from circuit diagram 220 that the input marked positive (pin 3) is connected to an unchanging voltage of ca. −1.6V (with respect to ground) (the voltage is produced by the stable forward voltage of the LED). The input marked negative, on the other hand, (pin 2) is connected to the slide of the potentiometer.

Fig. 220 Simple comparator


S
C1
+
100µF
A
LED1
K
h
P1
s
n
10kΩ
2
3
−
+
OP
6
Rv2
100Ω
LED2
A
K
Rv1
470Ω
V
+
A
−
E
UB
+
−
9V

When the potentiometer knob is turned completely to the left both LEDs are illuminated (LED1 will continue to be alight because it is only there to produce a stable voltage of -1.6V). Now turn the potentiometer to the right, the voltage at the slide increases. When the slide voltage becomes the same or fraction greater than −1.6V then LED2 goes out. The comparator "tips" i.e. its output changes from a positive to a negative voltage (with respect to ground). The LED is now being supplied in its nonconducting direction and cannot light up.

Turning the potentiometer knob back tips the comparator in the other direction again and LED2 lights up. There is no middle of the road. On or off, in or out, smaller or greater than −1.6V. An unequivocal statement from your operational amplifier. (If you are very careful you may sometimes to able to adjust the potentiometer so that the LED flickers on and off, or becomes slowly darker. This is because the operational amplifier has a tendency to oscillate at the switching point.)

Let us summarize the results of this experiment and also clarify a few important points concerning the properties of operational amplifiers:

1. The operational amplifier can produce positive or negative voltages at its output. It is permissible to speak of positive and negative voltages, because we are taking the ground = 0V as our reference point. You could compare a positive voltage with a positive height above sea level (sea level taken as zero) and a negative voltage with a depth below sea level. Both can be the same number of meters but they have different signs with respect to sea level. So the operational amplifier has not one but two **saturation points**, a positive one at ca. +3V and a negative one at ca. −3V.

2. The operational amplifier has an input differential amplifier and hence two inputs (see Section 13.4).

It amplifies the voltage difference at its inputs by a factor of 100000 to 200000. Because of the high amplification factor the smallest voltage differences are sufficient (theoretically) to push the output to either positive or negative saturation without any intermediate values.

3. The operational amplifier can invert. This means the alteration of the sign of the voltage (Fig. 221).

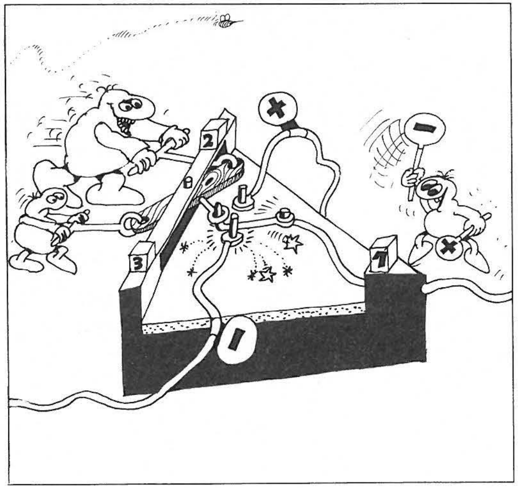


Fig. 221 The inverting operational amplifier; when the little man at the inverting input 2 pushes harder (higher positive potential) then the output goes to negative saturation. The imaginary model also works when the little men pull (negative potentials).

Which input voltage is inverted, that at pin 2 or that at pin 3? Since the operational amplifier can only react to voltage differences we have to consider both voltages in order to answer this question. Neither must it be forgotten that, just like the output voltage, the input voltages are always referred to ground voltage (0V).

Let us first look at pin 2, which is known as the inverting input (labelled with a minus sign in what follows) and calculate the difference between the input voltages.

Let us do it in the following order:

Voltage at pin 2 minus voltage at pin 3.

If this difference has a **positive sign** then the output goes to **negative saturation**. If the difference is **negative**, then the output goes to **positive** saturation. Thus the operational amplifier inverts the sign of the difference of its input voltages! Pin 3 is known as the noninverting input and is labelled with a plus sign.

Example from the comparator experiment:

Let the slide voltage, and hence the voltage at the inverting input 2, be −1.7V, the voltage at pin 3 is fixed at −1.6V.

The voltage at pin 2 (−1.7V) minus the voltage at pin 3 (−1.6V) = −0.1V. The difference has a negative sign, the output goes positive (the LED illuminates)!

You have now got to know the most important properties of operational amplifiers, and you may well have asked yourself what use amplification of 200000 is to you.

The answer is simple. The comparator is only one of many operational amplifier applications, where an extremely high amplification is useful. You will see later that it is possible to "adjust" to any required amplifications by means of a dodge, yes even an operational amplifier with an amplification of one is of very great interest.
In the next section we will look at some important comparator applications. You will see how it is possible to build flip-flops, note generators and monoflops with a comparator control circuit.

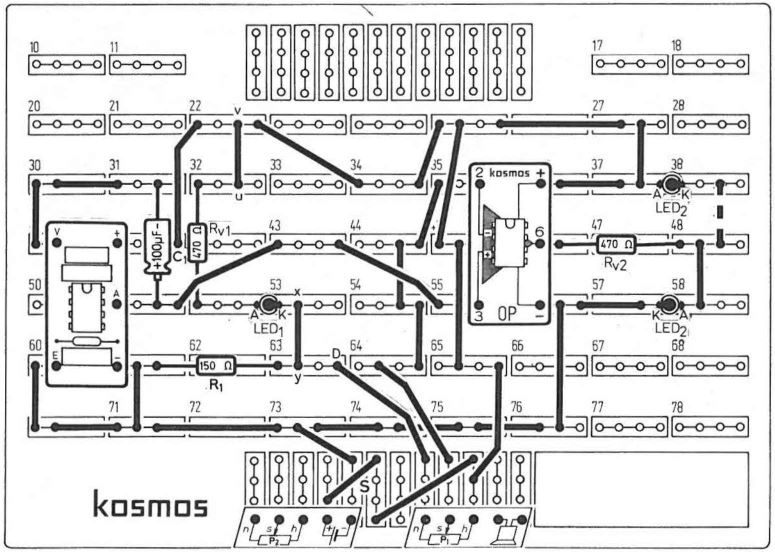

10
11
17
18
20
21
22
v
27
28
30
31
32
u
33
34
35
2 kosmos +
37
38
A K LED2
+100µF
C1
470 Ω
Rv1
43
44
6
47
470 Ω
Rv2
48
50
A
53
x
A K
LED1
54
55
57
58
K A
LED2
3 OP −
60
E
62
150 Ω
R1
63
y
D
64
65
66
67
68
71
72
73
74
75
76
77
78
S
n s h
P2
P1
kosmos

Fig. 222 Construction of circuit 223

17.6 Comparator applications – trust is good, control is better

What driver has not seen an automobile in front of him where only one taillight or brake light was working? This immediately makes him wonder if the lights of his own automobile are working and he would like a control device which would tell him whether his brake lights and taillights are in good order. We will now build such a control device.

17.7 Taillight warning

The circuit is constructed as in Fig. 222. You can recognize the operational amplifier in circuit diagram 223, its output controls LED2 via a resistance (ignore the LED on the broken circuit for the moment). The combination of LED1 and its protective resistor represents the taillights of an automobile.

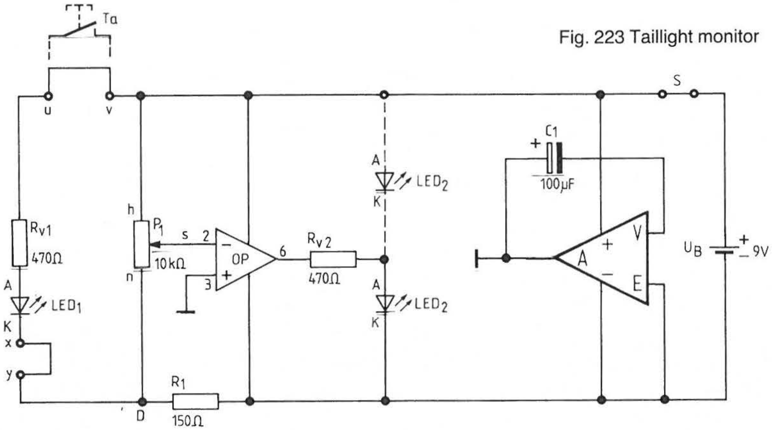

Ta
u
v
S
Rv1
470Ω
A
LED1
K
x
y
h
P1
s
2
10kΩ
n
3
OP
6
Rv2
470Ω
A
LED2
K
A
LED2
K
R1
150Ω
D
C1
+
100µF
A
+
V
−
E
UB
+
− 9V

Fig. 223 Taillight monitor

When the supply voltage is applied, then the "tail lamp" lights up and remains alight. LED2 can then be switched either on or off by adjusting the potentiometer.
Adjust the potentiometer so that LED2 – your warning light – lights up. Then carefully turn the knob of P1 back until the warning light goes out. Now simulate the burning out of the taillight by removing the connector x-y. The warning light will immediately go on.

17.8 Brake light warning

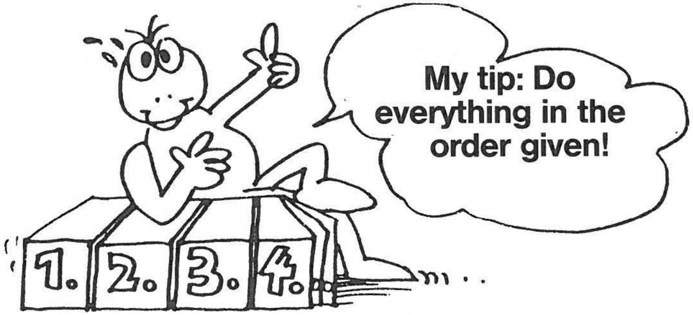
The circuit in Fig. 223 can simulate a brake light warning if you change it slightly: remove LED2, and replace it to the left of the wire connector shown with a broken line in Fig. 222, then replace connector u-v by a contact maker. Finally make sure the connector x-y is in place. LED1 only lights up now when the contact maker is pressed down. It represents the brake pedal and the combination of LED and protective resistor represents the brake light.
The warning light is adjusted by means of P1 when the contact maker is pressed down. First turn the potentiometer until the control LED2 goes out and then (still pressing the contact maker) turn it slowly back so that the lamp goes on again. Leave go of the contact maker and LED1 and LED2 will go out simultaneously. Simulate the burning out of the brake light by removing connector x-y. The warning light now remains out when the brakes (contact maker) are used.

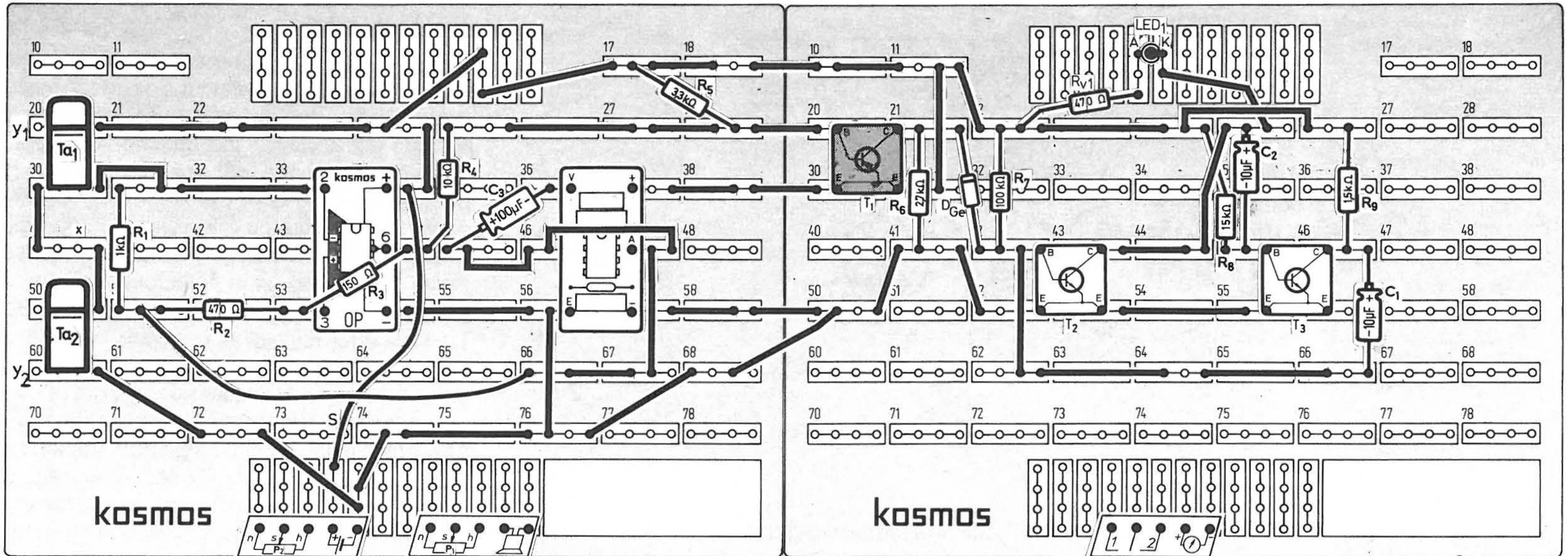
17.9 Comparator in a control function

The operational amplifier is connected as a comparator in both of the control circuits; however, input 3 is now grounded. This means that the voltage at the inverting input is compared with 0V. The 150-Ω-resistor plays a crucial role in this circuit. If current is not flowing through (LED1 out), then point D in the circuit 223 is at the negative supply voltage (ignoring the tiny current through the potentiometer). If, on the other hand, LED1 is illuminated, then its current must pass through the 150-Ω-resistor, which leads, in accordance with Ohm's law, to a voltage drop across the resistor. This voltage drop alters the slide voltage of the potentiometer and hence the comparison voltage at the inverting input and tips the comparator – providing the potentiometer was properly adjusted in the first place.

17.10 For model railroaders – an automatic signal for unprotected crossings

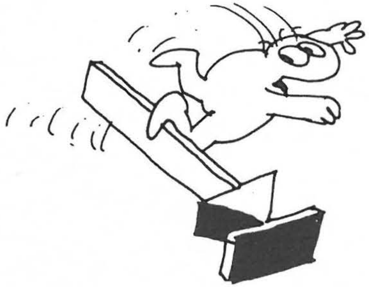
An operational amplifier operated as a comparator can be converted to a real flip-flop merely by adding three resistors, as shown on the left-hand side of Fig. 225. In order to allow the flip-flop to switch something interesting on and off, an astable multivibrator is made up from transistors and the whole is employed as an automatic warning blinker for an unprotected model railroad crossing; it switches on as soon as the train approaches and when the train is over the crossing the electronics switches the blinker off again.

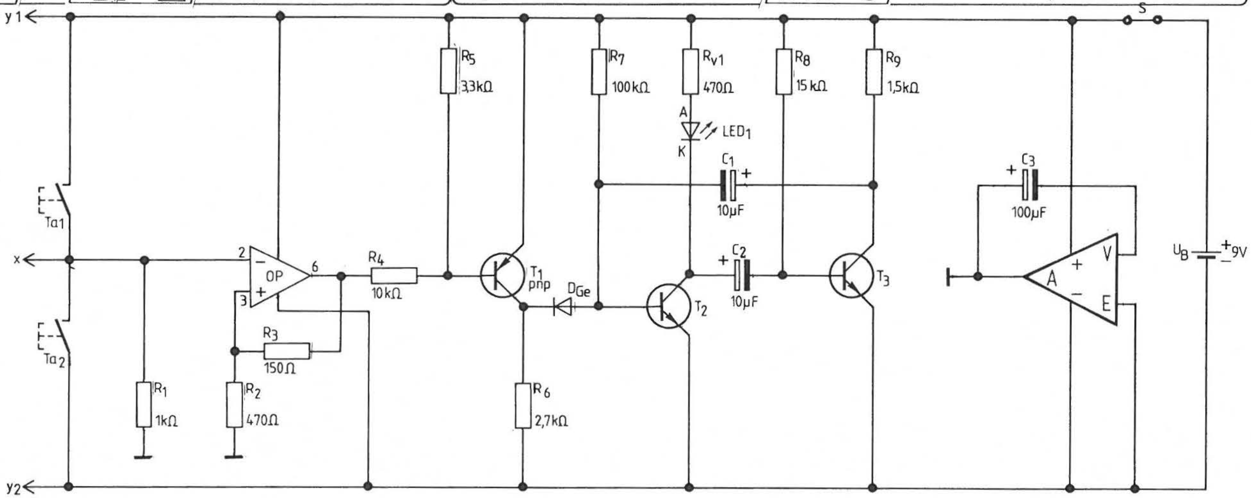

My tip: Do everything in the order given!
1.
2.
3.
4.



y1
y2
x
Ta1
Ta2
R1
1kΩ
R2
470 Ω
R3
150 Ω
2 kosmos +
6
3 OP -
R4
10 kΩ
C3
+100µF-
V
A
E
R5
3,3kΩ
T1
R6
2,7kΩ
DGe
R7
100 kΩ
Rv1
470 Ω
LED1
A K
C2
10µF
R8
15kΩ
R9
1,5kΩ
T2
T3
C1
10µF
S
kosmos
kosmos
P2
P1
n s h

Fig. 224 Construction of circuit 225





y1
x
y2
S
Ta1
Ta2
R1
1kΩ
R2
470Ω
2
3
OP
6
R3
150Ω
R4
10kΩ
R5
3,3kΩ
T1
pnp
R6
2,7kΩ
DGe
R7
100kΩ
Rv1
470Ω
A
LED1
K
C1
10µF
T2
C2
10µF
R8
15 kΩ
R9
1,5kΩ
T3
C3
100µF
A
V
E
UB
+9V

Fig. 225 Blinking light for model railroad

We simulate the approach of the train in construction 224 by pressing contact maker Ta1 down. The blinker begins to work. It is stopped again by pressing contact maker Ta2.

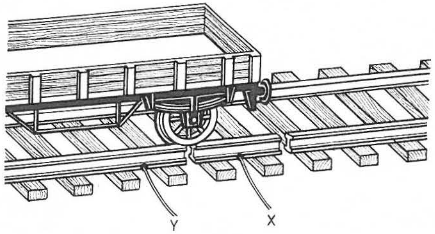


Fig. 226 Example of the use of the blinking light in model railroad practice

17.11 Comparator as flip-flop

When the supply voltage is applied the output of the operational amplifier in Fig. 225 is in either positive or negative saturation; which this will be, cannot be predicted. So we can base our explanation of the operation of the circuit on either of the two states, e.g. +3V. The 150Ω and 470Ω resistors connect the output with ground. The voltage between the two resistors is ca. +2.5V. This voltage is applied to the noninverting input (pin 3). Pin 2 is connected to ground via a 1kΩ-resistor and is thus at 0V. Now 0V is considerably less than +2.5V (0V minus 2.5V = −2.5V). Therefore the inverting input is at the lower voltage; so the output remains at the positive saturation.

What happens now when contact maker Ta1 is depressed?

Pin 2 is connected to the supply voltage of +4.5V for a short time. This completely changes the relationships. There is now a larger voltage at the inverting pin 2 than at pin 3 (+4.5V minus +2.5V = +2.5V); the comparator switches, the output goes to negative saturation. If the contact maker is released then pin 2 returns to ground. But since the polarity at the output has been reversed, pin 3 is now at −2.5V. So that the voltage at the inverting input is larger and the output remains at negative saturation. If contact maker Ta2 is depressed, then the process takes place in the opposite direction. The purpose of the p-n-p transistor T1 between the operational amplifier flip-flop and the blinker transistor is merely to produce a voltage necessary to block the blinker; the negative saturation voltage of the operational amplifier would not be sufficient for this.

17.12 FFF – flicker-fusion frequency

The human eye is sluggish. Luckily, otherwise a movie would be an irritating procession of rapidly changing pictures. The frequency at which you begin to see a lamp that is continually switched on and off as continually bright is known as the "flicker-fusion frequency".

Figure 228 shows a simple apparatus for the production of variable frequencies. The operational amplifier comparator in the left-hand side of the circuit is connected as an astable multivibrator, the flip-flop made up of the two transistors halves the frequency produced and ensures that the periods of light and darkness are equal in length (duty factor 1:1). Frequencies between ca. 50 and 500 Hz can be generated by turning potentiometer P2 – the half of which is received by the LED.

Before you flicker-test your eyes let us take a close look at the secrets of the frequency generator. Consider the moment of application of the working potential. As usual we will assume that the output of the operational amplifier lies at the positive saturation level; then there will be a positive voltage at pin 3 determined by the ratio of the resistors *R*1 and *R*2 (in our case it is about +2V). Since both 0.1-μF-capacitors are uncharged at the moment of switching on, there is a voltage of 0V for a moment at pin 2. So the relationships are now clear; a smaller voltage at the inverting input holds the output at positive saturation. However, the capacitors begin to charge via *R*3 and the potentiometer P2. This carries on so long as the charging voltage (that is the voltage at pin 2) is below ca. +2V. Even if this voltage is only slightly exceeded, the comparator mechanism comes into action. The output changes from positive to negative saturation and now the relationships change over. There is a voltage of ca. −2V at pin 3 and the voltage at the inverting input is therefore larger than that at the noninverting pin 3, the output remains at negative saturation and the

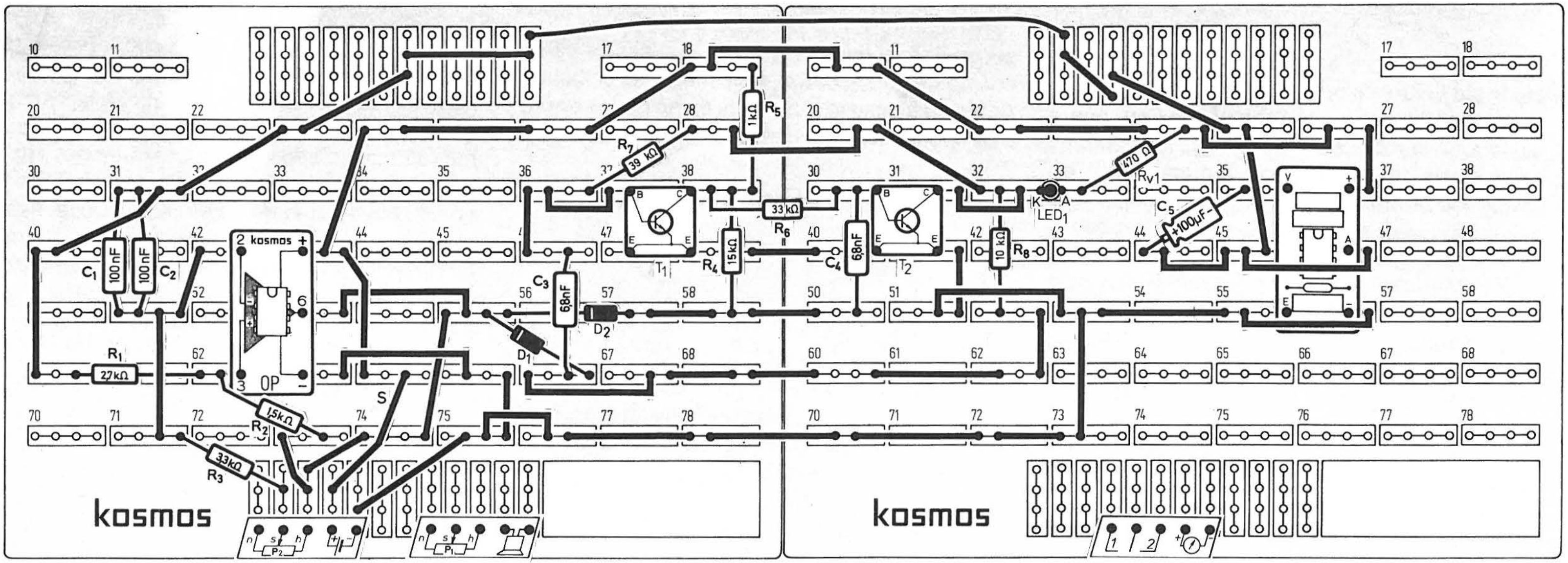

kosmos
kosmos
C1
100nF
C2
100nF
R1
27kΩ
2 kosmos +
6
3 OP -
R2
15kΩ
R3
33kΩ
S
P2
P1
D1
D2
C3
68nF
R7
39 kΩ
R5
1kΩ
T1
R4
15kΩ
33 kΩ
R6
C4
68nF
T2
R8
10 kΩ
K
A
LED1
470 Ω
Rv1
C5
+100µF
1
2

Fig. 227 Construction of circuit 228

capacitors begin to charge in the opposite direction, until the charging potential reaches a value that is smaller than −2V. As you can see this circuit will never come to rest...

Suggestions for experiments:
You can find the flicker-fusion point by turning P2 very slowly from its left-hand stop to the right, until you get the impression that the light is constant (look down on the LED from above!). Note the setting and then turn P2 to the right-hand stop and turn it towards the left until the diode seems to flicker again. Both determinations should be made several times. Now carry out the experiment at various times of day. You will be able to see that the flicker-fusion frequency is lower when you are tired than when you are alert.
It can be shown that age has an effect by testing various people. How do tea, coffee and (for adults) the consumption of alcohol or a cigarette affect the FFF?

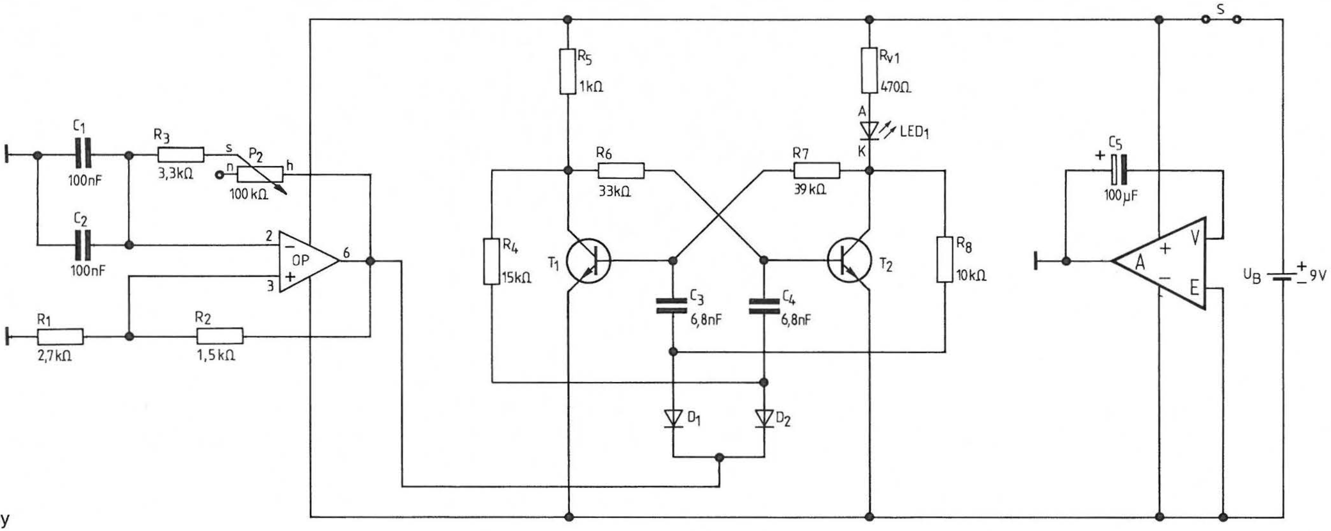

C1
100nF
R3
3,3kΩ
s
P2
n
h
100 kΩ
C2
100nF
2
OP
6
3
R1
2,7kΩ
R2
1,5kΩ
R5
1kΩ
Rv1
470Ω
A
LED1
K
R6
33kΩ
R7
39 kΩ
R4
15kΩ
T1
T2
C3
6,8nF
C4
6,8nF
R8
10kΩ
D1
D2
C5
100µF
+
A
V
E
UB
+9V
S

Fig. 228 Flicker-fusion frequency

17.13 Comparator with “long leads“ – monoflop

Only one component has to be added to the astable multivibrator to make it behave in a monostable manner. The diode in Fig. 230 stops pin 2 becoming negative so that at the beginning when the contact maker is pressed the output is in positive saturation (the diode then blocks the flow of current), however, when the capacitor has finished charging the circuit returns to its resting condition and stays there until the contact maker is pressed again (construction Fig. 229). The delay times that can be achieved by means of an operational amplifier monoflop are significantly greater than with a transistor circuit.

Fig. 230 Monoflop with OP AMP

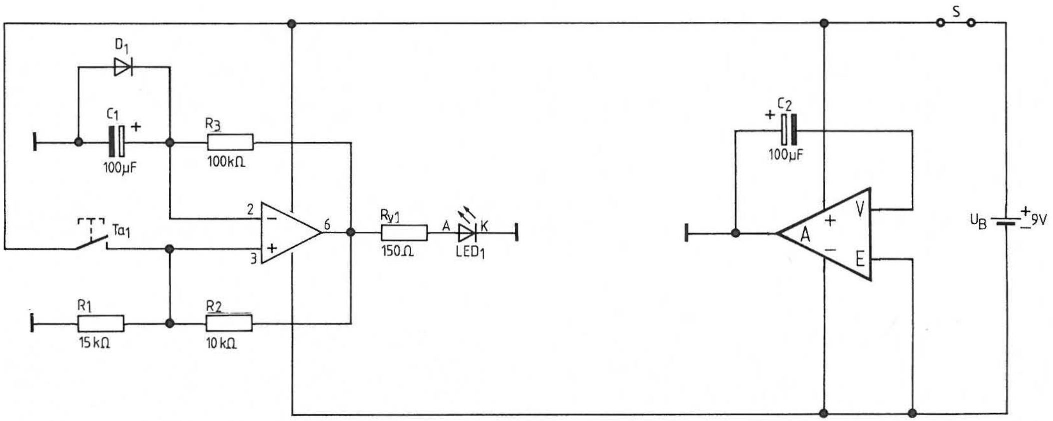
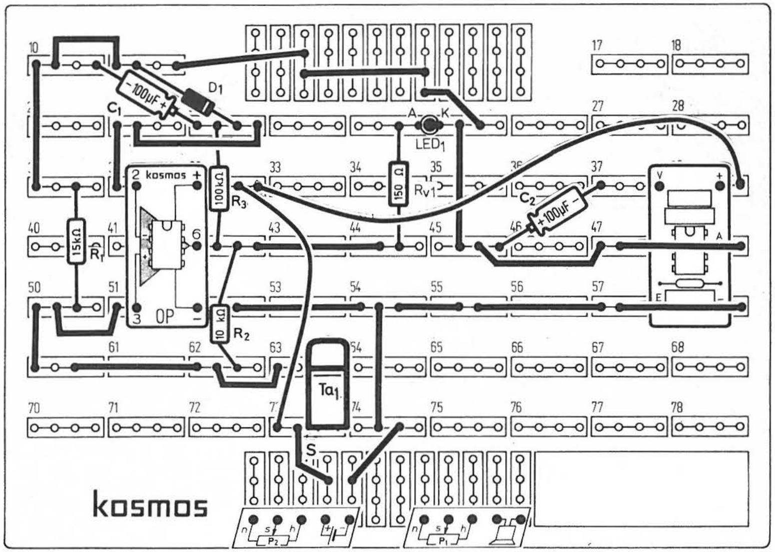

D1
C1
+
100µF
R3
100kΩ
Ta1
2
3
6
Rv1
150Ω
A
K
LED1
R1
15kΩ
R2
10kΩ
C2
+
100µF
A
+
−
V
E
UB
+9V
S

Fig. 229 Construction of circuit 230


10
17
18
27
28
D1
C1
100µF
A
K
LED1
33
34
35
37
40
41
43
44
45
46
47
50
51
53
54
55
56
57
61
62
63
65
66
67
68
70
71
72
74
75
76
77
78
2 kosmos +
100kΩ
R3
150 Ω
Rv1
C2
+100µF
V
A
E
15kΩ
R1
6
3 OP
10 kΩ
R2
Ta1
S
kosmos
P2
P1

Suggestion for experiment:
Various values can be tried out for resistor *R*3 in combination with 10-μF- and 100μF-capacitors. With 220kΩ and 100μF the delay time is ca. 17 seconds.
The LED can be turned round and then the whole circuit functions as a switch-on delay (when the contact maker is depressed the LED goes out and only comes on again when the delay time is over). This form of monoflop circuit is often employed in electronic alarms which have a "snooze" knob that has to be pressed when the alarm goes off, for real sleepyheads who would like to lie in for a couple of minutes. After the delay time the alarm goes off again and so on.

18. Measurement techniques – Part 1

18.1 The force that bends spoons

Electronics naturally has nothing to do with telekinesis or spiritualistic seances and, hence, a very strong current indeed must flow through a spoon, if it is going to bend. But, nevertheless, it will bend because every conductor, through which a current is flowing, is surrounded by a magnetic field and where there is a magnetic field there is also a force.
The effect of magnetic forces is exploited, for instance, in the moving coil meter that is illustrated schematically in Fig. 231.

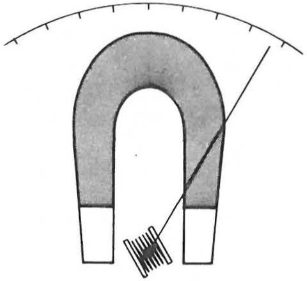


Fig. 231 Diagram of a moving coil meter

A coil of hair-fine wire can rotate between the poles of a horseshoe magnet. If a current flows through the coil then it creates an additional magnetic field, whereby the north pole is attracted to the south pole and north and north poles or south and south poles repel each other. The coil and the pointer move backwards and forwards.

At the same time a little spiral spring is put under tension, so that the pointer comes to rest when the force exerted by the spring equals the magnetic force. The displacement of the pointer corresponds to the current flowing through the coil.
Figures 232 and 233 show the actual construction of a meter.

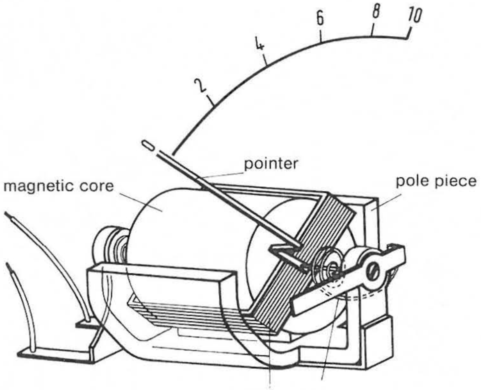


Fig. 232 The permanent magnet lies inside, the coil rotates around it

You can recognize the movable coil again, here it is wound on a thin frame. The pointer is attached to this frame and opposite it a counterweight to compensate for the weight of the pointer, so that the reading given by the meter is more or less independent of the position of the meter.
The permanent magnet (horseshoe magnet in our representation), is, astonishingly, not outside but inside the coil as a magnetic core. The coil rotates around the magnet.

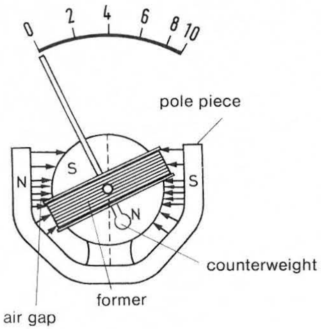


Fig. 233 A meter in practice

In order to make sure that the magnetic lines of force are properly directed a yoke of magnetic material is fixed round the outside of the coil; this ensures that the lines of magnetic force are mainly concentrated in the narrow air gap, within which the coil can rotate.
The lines of magnetic force are represented as (imaginary) arrows. Because of the differing shapes of the magnet core and yoke the lines of force are more intense halfway up where the air gap is somewhat narrower. The varying thickness of the air gap results in an expansion of the scale. The expansion of your meter is subject to a certain tolerance.

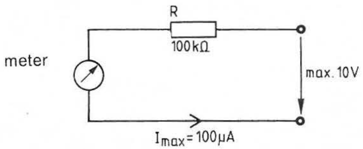
18.2 Resistance inside

The coil of hair-fine wire in your meter has a resistance of 1200 ohm (1.2kΩ). This is known as the **internal resistance** of the instrument. Its magnet is so arranged that the pointer is displaced by 10 scale graduations (full scale deflection) when a current of 100µA flows through it. So according to Ohm's law there is then a voltage drop across the instrument corresponding to:

$$U = I \cdot R = 0{,}0001 \cdot 1200 = 0{,}12\ \text{V}$$

This knowledge will help us later when the little instrument is employed for measuring voltage drops. Imagine that you have to measure voltages of up to 10V (thus one scale graduation = 1V), then all that has to be done is to calculate what size of resistor must be connected in series with the meter so that a voltage drop of 10V across the sum of the resistor and the meter's internal resistance causes a current of 100µA to flow through. Here Mr. Ohm helps us once again. That is:

$$U = 10\ \text{V} = I \cdot R = 100\ \mu\text{A} \cdot (R_v + R_i)$$
$$R_v = 100\ \text{k}\Omega - R_i = 98{,}8\ \text{k}\Omega$$



Accepting an error in the choice of the series resistance of 1% we set *Rv* as 100kΩ. Figure 234 illustrates the circuit diagram of our meter for measuring voltage differences of up to 10V.

18.3 Current branching and Kirchoff's laws

Newcomers to electronics often find it difficult to "read" a circuit diagram, i.e. to recognize the function of a circuit. In the following sections you will be introduced to some illuminating ideas and rules, which are sure to be a great help to you in evaluating unknown circuits.

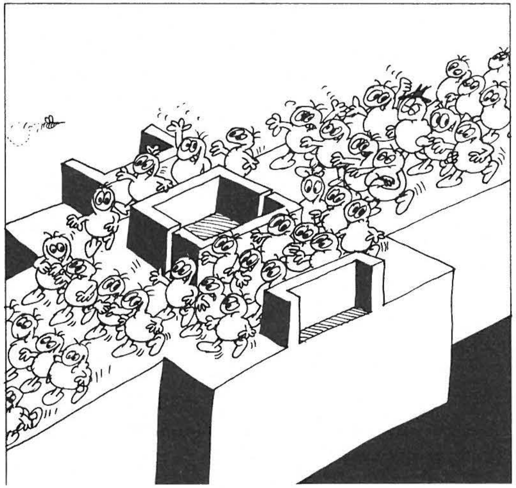


Fig. 235 Current branching: The total current is the sum of the partial currents.

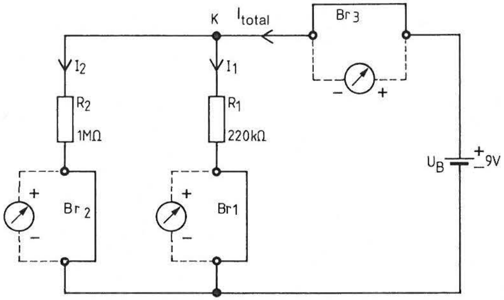

K
I total
Br 3
I2
R2
1MΩ
I1
R1
220kΩ
UB
+
9V
Br 2
Br1
+
−

Fig. 237 Measurements at a current branch

18.4 March separately, attack together

You can apply this battle strategy to electrons, when more current has to flow than a single resistor can cope with. The tactical measure is to offer the current a second path. This is possible by connecting resistors in parallel (Fig. 235).
Three measurements are to be made in the next experiment, by removing the appropriate connectors and connecting the instrument instead (Fig. 236, construction 237).

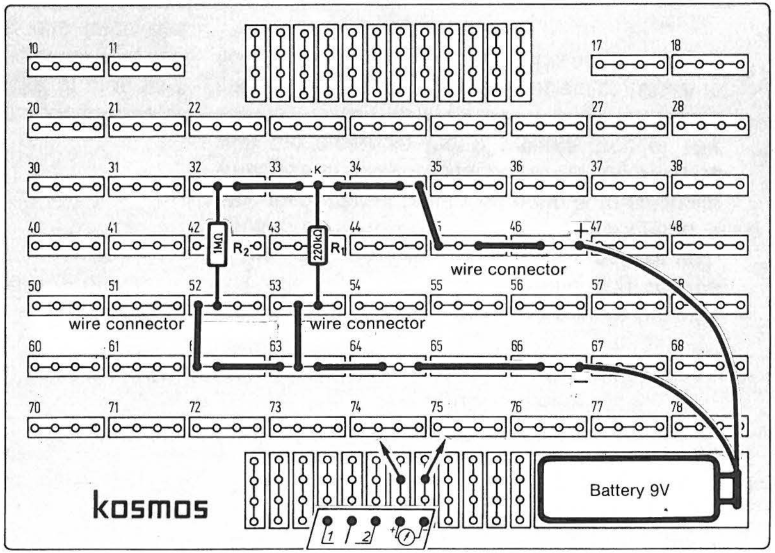

K
1MΩ
R2
220kΩ
R1
wire connector
wire connector
wire connector
+
−
Battery 9V
kosmos
1
2

Fig. 236 Construction of circuit 237

Approximately 41μA flow through the 220-kΩ-resistor (= 4.1 scale graduations on the meter), additionally 9μA flow through the 1-MΩ- resistor as the meter will confirm by measuring at point 3. The sum of these two gives us the combined current, that is ca. 50μA. The following formula for the total current can be directly deduced from the measurements:

(F18) $I_{tot} = I_1 + I_2$

Substituting in formula 18 according to Ohm's law

$$I_1 = \frac{U}{R_1} \text{ und } I_2 = \frac{U}{R_2}$$

we get

$$I_{tot} = \frac{U}{R_1} + \frac{U}{R_2} = U \cdot \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$R1 = 1\ \text{M}\Omega$, $R2 = 220\ \text{k}\Omega$

$$R_{tot} = \frac{1\ \text{M}\Omega \cdot 0{,}22\ \text{M}\Omega}{1{,}22\ \text{M}\Omega} = 0{,}18\ \text{M}\Omega = 180\ \text{k}\Omega$$

(F19)

The total resistance of a parallel connection is

$$R_{tot} = \frac{U}{I_{tot}} = \frac{U}{U \cdot \left(\frac{1}{R_1} + \frac{1}{R_2}\right)} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

So the same effect is obtained by connecting a 1-MΩ- and a 330-kΩ-resistor in parallel as if a single 180-kΩ-resistor were employed. The strategy "march separately, attack together" allows the realization of many different values by the employment of only a few resistors. If the problem arises of finding out what resistance Rx should be connected in parallel with a known resistor $R1$ in order to attain a desired total resistance then the answer can be obtained by rearranging Formula 19 so that the value of the unknown resistor can be calculated immediately:

(F20) $$R_X = \frac{R_1 \cdot R_{tot}}{R_1 - R_{tot}}$$

18.5 The current takes the path of least resistance

You saw in the measurements earlier that the higher resistance carried less current, that more current passed through the lower resistance. Thus the currents act reciprocally to the resistance:

(F21) $I_1 : I_2 = R_2 : R_1$

18.6 Mr. Kirchhoff's laws

After the results you obtained in the previous section **Kirchhoff's first law** will sound trivial to you: "At any junction of several conductors the sum of the current flowing in, is equal to the sum of the current flowing out".

In the case of our junction K in Fig. 237 I_{tot} (50μA) flows in and flows out in separated streams as $I1$ (41μA) and $I2$ (9μA). This is known as current branching.

If the current flowing into a junction is given a positive sign and that flowing from it a negative sign, then the sum of the currents at any junction is always zero.

This law was formulated by the German physicist Gustav Robert Kirchhoff (1824-1887) who made a detailed study of current branching.

Mr. Kirchhoff also formulated a second law; this refers to voltages and voltage drops in electrical circuits. It reads: "The sum of all potentials in a closed circuit equals zero" or

(F22) $U_1 + U_2 + U_3 \ldots = 0$

This law too can be checked by means of a few measurements. The necessary construction is shown in Fig. 238, the circuit diagram in 239. The meter will now be employed as a volt meter with a 10V full scale deflection; measure the voltage drop in each of the resistors one after the other.

You will get the following values:

Resistance	**Voltage drop**
$R1$	5.5V
$R2$	6.4V
$R3$	0.9V
$R4$	2.6V

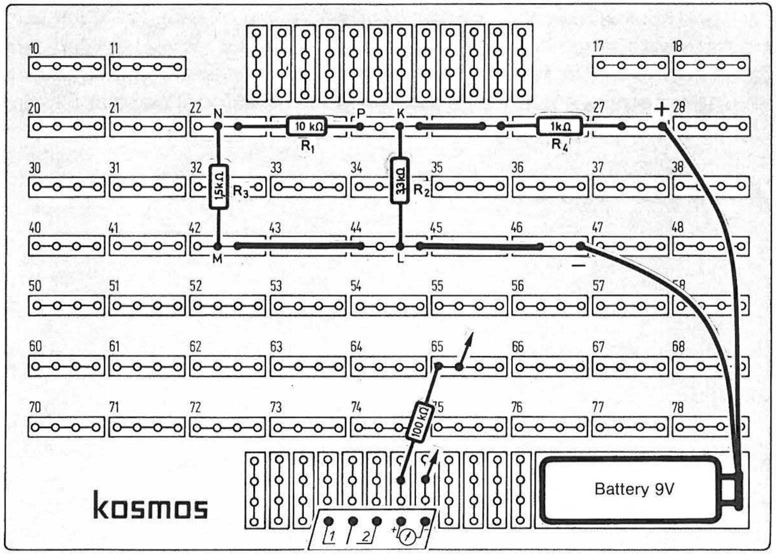

10
11
17
18
20
21
22
N
10 kΩ
R1
P
K
1kΩ
R4
27
+ 28
30
31
32
15kΩ
R3
33
34
3,3kΩ
R2
35
36
37
38
40
41
42
M
43
44
L
45
46
47
48
–
50
51
52
53
54
55
56
57
58
60
61
62
63
64
65
66
67
68
70
71
72
73
74
100kΩ
75
76
77
78
kosmos
Battery 9V
1
2

Fig. 238 Construction of circuit 239

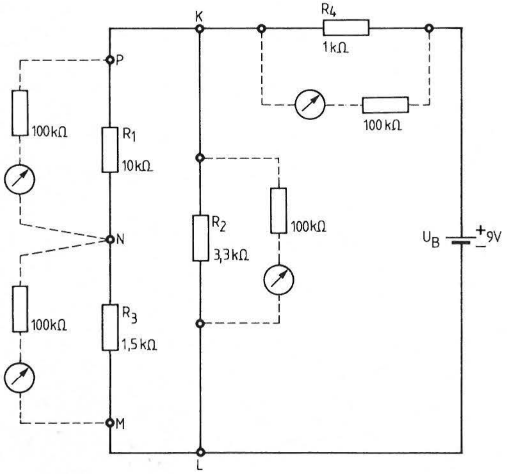

K
R4
1kΩ
P
100kΩ
100kΩ
R1
10kΩ
N
R2
3,3kΩ
100kΩ
UB
+9V
100kΩ
R3
1,5kΩ
M
L

Fig. 239 Measurements in various networks

18.7 A little "network aid"

In order to be able to interpret the measurement results, we need a little "aid" concerning how to use Kirchhoff's second law:

1. A closed circuit is known as a network irrespective of whether it contains a voltage source or is merely a network of resistors.
2. Voltages (voltage drops across resistors, battery voltages) are marked in the network with a directional arrow.
3. The numbered arrows are drawn in the direction of conventional current flow.
4. If, as you trace round the network, you meet an arrow head-on, then the voltage involved is assigned a negative sign; if it is the tail of the arrow that you come to first then the associated voltage is assigned a positive sign for purposes of calculation.

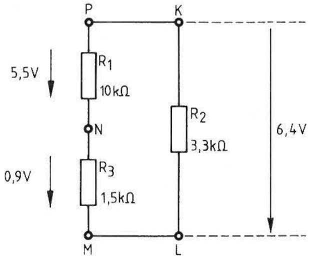

P
K
5,5V
R1
10kΩ
N
R2
3,3kΩ
6,4V
0,9V
R3
1,5kΩ
M
L

Fig. 240 Consideration of a single network

The employment of this "aid" to the network KLMNP in Fig. 240 gives:
Starting at K in direction L

Numbered arrow points in the direction of motion, so calculate 6.4V positive.
No voltage drop from L to M
From M via N to P two arrows in the opposite direction to the direction of motion, calculate two voltage drops of 0.9V and 5.5V negative. No voltage drop from P to K.

The sum of all the potentials in the network is:
$6.4V + (-0.9V) + (-5.5V) = 0V$

The calculation also works out, of course, for any other possible networks, e.g.
Positive pole of battery – K – L – negative pole of battery:

Positve pole of battery to K	+2.6V
K to L	+6.4V
L to negative pole	0V
Negative pole to positive pole	−9.0V
Total	0V

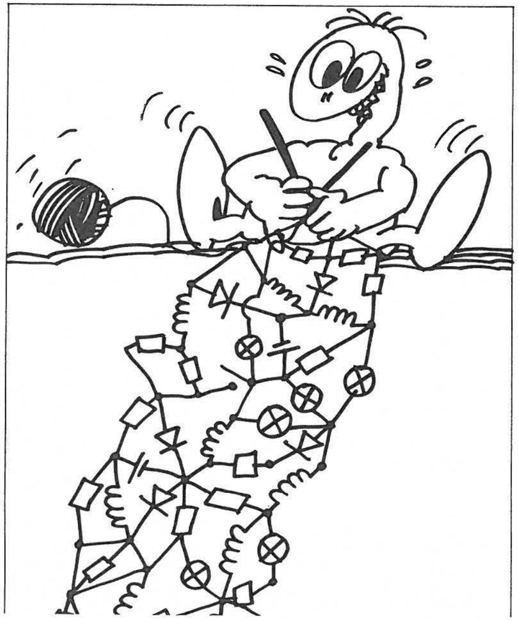


Fig. 241 The word network is very often employed in electrical technology; in electronics reference is sometimes made to a "knitted circuit" (with a very "wild" construction).

19. Easy to handle – the tamed operational amplifier

Now that you have acquired all this knowledge about current and network rules, you can begin to control the enormously high amplification of the operational amplifier, by fitting it with a corset of resistors, which you can make to fit your purpose.

19.1 The inverting amplifier

In the comparator circuit the operational amplifier was able to exhibit its full amplifying capacity without any restraints; even small potential differences at the inputs led to saturation of the output. This property is desirable for comparator applications, but not if you wish, say, to use an operational amplifier to amplify a certain potential by precisely 10-fold.

The operational amplifier can be tamed by negative feedback; this means that the output signal opposes the input signal. In order to make this process understandable let us consider the following system (Fig. 242).

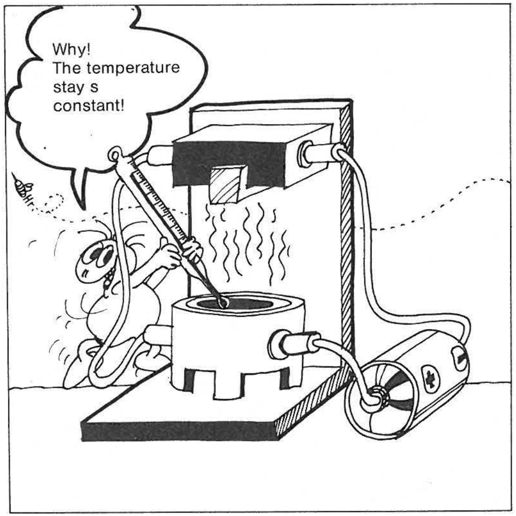

Why!
The temperature
stay s
constant!

Fig. 242 A control loop with negative feedback: When the hot plate gets hotter, the resistance of the metal block increases and the current drops.

The temperature of a hot plate connected to the mains power supply is to be kept constant independent of what happens in the surrounding environment. In order to do this a metal block is placed on the hot plate and the resistance of this metal block increases with increasing temperature. The resistance of the metal block is electrically connected in series with the hot plate. A regulation process is set in motion; when the temperature of the hot plate rises, then the resistance of the metal block becomes greater. This causes the current to decrease and the hot plate is not so hot. If the hot plate is cooled down, then the resistance of the metal block is reduced and so more current flows and the heat supply to the hot plate is increased.

At a particular supply voltage an equilibrium will be set up and the temperature will remain constant. Such a **control loop**, where the output variable (heat) exerts a negative effect on its own cause (current), is achieved in the case of the operational amplifier by connecting a resistor between the output of the operational amplifier and its inverting input. This feedback is negative because the output of the OP AMP is of the opposite sign to its inverting input (when the other input is at ground potential).

The basic circuit for an inverting amplifier with a fixed amplification factor is shown in Fig. 243. Only the tiniest voltage differences may occur between the inputs if the output is not to go to saturation. In the negative feedback principle a particular output voltage itself sets that tiny input voltage, that is necessary for its own creation.

How high is the amplification factor in Fig. 243 then?

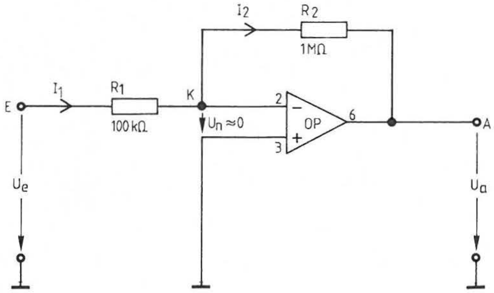


Fig. 243 The inverting amplifier in terms of networks

Since we wish to amplify the potential then:
amplification =
output voltage/input voltage
or

(F23) $$V = \frac{-U_o}{U_i} = \frac{R1}{R2}$$

We can obtain the relationships for *U*o and *U*i from the Kirchhoff network rules:

1) $- U_o - I2 \cdot R2 + U_n = 0$
(Network : Ground – A – K – Ground)
2) $- U_i + I1 \cdot R1 + U_n = 0$
(Network : Ground – E – K – Ground)

If we assume that current is neither entering nor leaving the OP AMP input (in practice the current is only a fraction of a μA), then the current *I*1 that flows into the junction K must be just the same as current *I*2 that comes out of it (Kirchhoff's first law).

When it is further considered that *U*n (that is the voltage difference directly at the OP AMP pins) is very tiny, a large error is not introduced if *U*n = 0V is taken for both network equations. So we get:

$$- U_o - I \cdot R2 = 0$$
$$- U_i + I \cdot R1 = 0$$

From these two equations we then get:

$$\frac{- U_o}{U_i} = V = \frac{R2}{R1} \quad \text{or : } U_o = - U_i \cdot \frac{R2}{R1}$$

So we can set the OP AMP to any amplification factor we want by means of two quite ordinary resistors!

The most important properties of an inverting amplifier are:

1. Input and output voltages have opposite polarities, hence the negative sign in formula F23.
2. The applied voltage cannot only be amplified but also reduced, that is when *R*2 is smaller than *R*1.
3. Since the noninverting input is at ground and there is practically no voltage difference between the inputs, the inverting input is also practically at ground potential; it is referred to as a **virtual zero point**.

This is of importance when considering the input resistance; the actual high input resistance of the OP AMP does not come into play and *R*1 becomes the input resistance of the whole circuit.

In circuit 243 the amplification factor of the OP AMP can be calculated as follows:

$$V = \frac{R2}{R1} = \frac{1\ M\Omega}{100\ k\Omega} = 10$$

19.2 Signals from a potato

What can we now amplify by a factor of 10 with the amplifier in Fig. 243?
Something unusual but very interesting; you can use a normal potato to produce a very small voltage that can be detected with the aid of your amplifier. What do you need? A potato of course, then (with the kind permission of the lady of the house) a silver fork and an ordinary kitchen knife. Stick the knife and fork into the potato and con-

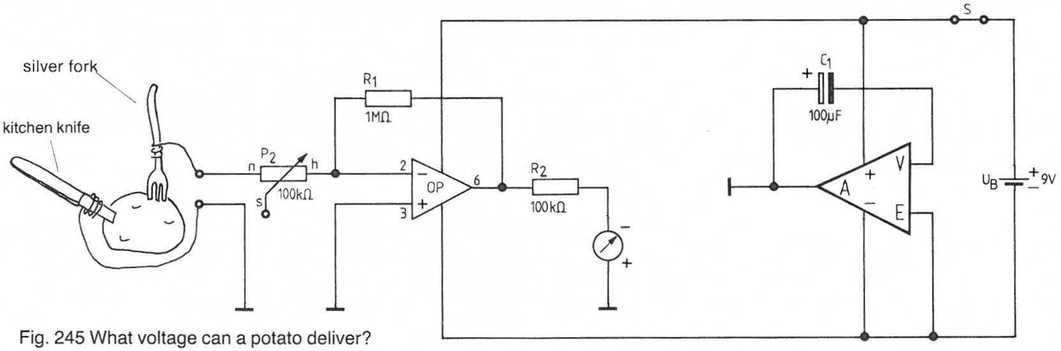
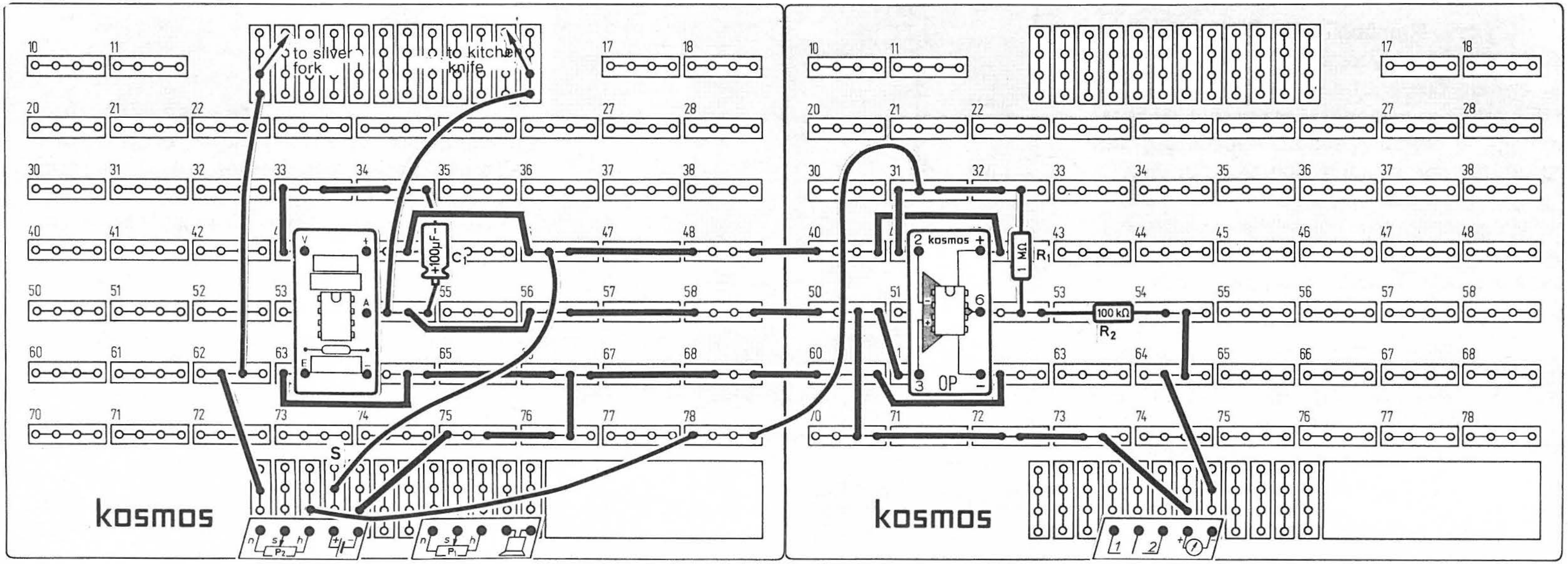

silver fork
kitchen knife
P2
n
h
s
100kΩ
R1
1MΩ
2
3
OP
6
R2
100kΩ
C1
100µF
A
V
E
S
UB
9V

Fig. 245 What voltage can a potato deliver?

Fig. 244 Construction of circuit 245


to silver fork
to kitchen knife
+100µF-
C1
V
A
E
S
2 kosmos +
3 OP -
6
1 MΩ
R1
100 kΩ
R2
P2
P1
n
s
h
kosmos
kosmos

nect their metal parts to the input of your amplifier, as shown in circuit diagram 245 and construction diagram 244. Note. In this circuit the potentiometer P1 works as a fixed resistor of 100kΩ, (the slide is not connected).

The meter will show a deflection of between 1 and 2 scale graduations, that is 1...2V at the amplifier output. So that this value has to be divided by the amplification factor (that is by 10) in order to establish the voltage of the potato; the humble spud delivers a voltage of between 100 and 200mV!

Incidentally the secret of the potato battery lies in the varying "nobility" of the metals; the silver of the fork is far more noble than the iron of the knife and the whole is nothing more or less than a galvanic cell to which the potato contributes an extremely weak acid.

19.3 The noninverting amplifier

Figure 246 shows the connections for a noninverting operational amplifier. The negative feedback principle is employed here too, however only a portion of the output is returned; *R*1 and *R*2 make up a voltage divider. Since the difference in voltage between the inputs is so small that it can be taken as zero, the voltage at the inverting input is practically the same as *U*i. The calculation is once again very simple (Kirchhoff's network rule):

$$1)\ -U_a + I(R1 + R2) = 0$$

$$2)\ -U_e + I \cdot R2 = 0$$

Thus the amplification is:

$$V = \frac{U_a}{U_e} = \frac{R1 + R2}{R2} = 1 + \frac{R1}{R2}$$

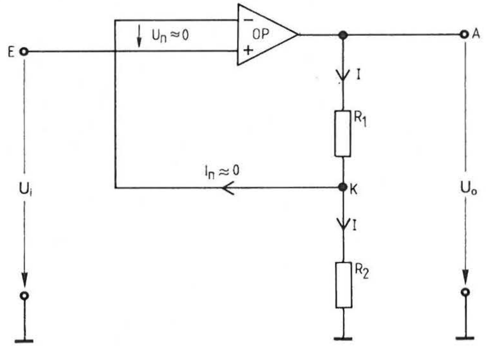


Fig. 246 The noninverting amplifier in network terms

What are the differences from the inverting amplifier?

1. Input and output voltages are of the same polarity.

2. It is not possible to set up the noninverting amplifier to give an amplification factor of less than 1, i.e. it is not possible to lower voltages.

3. The input resistance is extremely high.

Suggestions for experiments:

What the inverting amplifier can do with a potato the noninverting amplifier must be able to do too. The amplification factor in Fig. 248 is not exactly 10, rather the calculation yields 10.4; V = 1 + (940 divided by 100), but that is not important for the potato experiment. Two things are of interest to us:

1. Since the resistance of the circuit is so high, the input should not be left "open"; when the input is open the output goes to saturation. We have, therefore, included a switch with the functions measure and zero, to avoid this unpleasant effect.

2. With the inverting amplifier you can observe that the voltage gradually drops, in this case, however, the meter remains at one reading; the input resistance of the noninverting amplifier is so large, that the potato battery has to deliver practically no current to the measuring circuit.

19.4 An amplifier that does not amplify

The input resistance can be increased even further if the inverting input is connected directly to the output without an intervening resistor (Fig. 249). A check by means of Kirchhoff would show

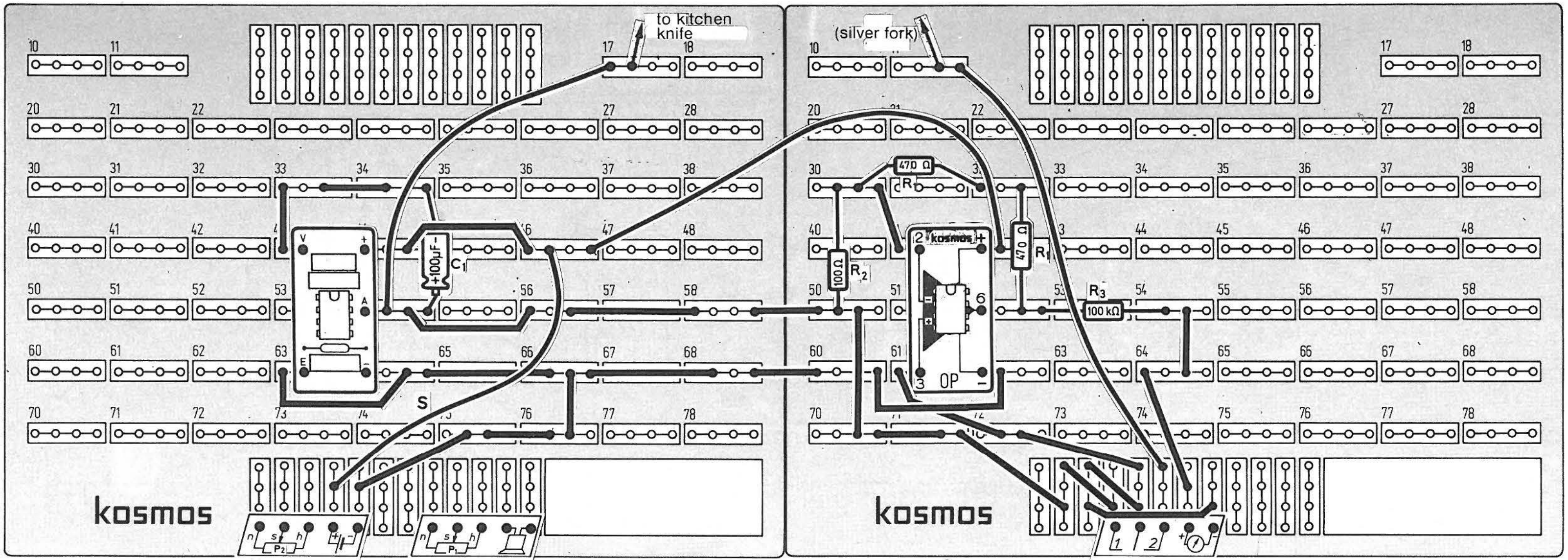
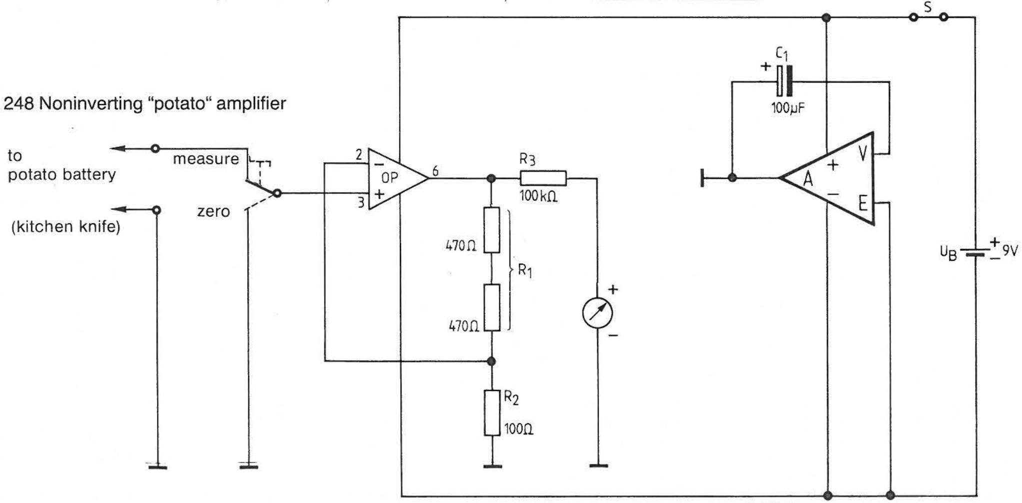

to kitchen knife
(silver fork)
C1
+100µF-
S
470 Ω
R
470 Ω
R1
100Ω
R2
R3
100 kΩ
kosmos
OP
2
3
6
V
A
E
P2
P1
1
2
kosmos
kosmos

Fig. 247 Construction of circuit 248

Fig. 248 Noninverting "potato" amplifier


to
potato battery
measure
zero
(kitchen knife)
2
3
OP
6
R3
100kΩ
470Ω
470Ω
R1
R2
100Ω
S
C1
100µF
A
V
E
UB
9V

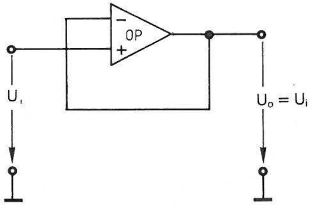


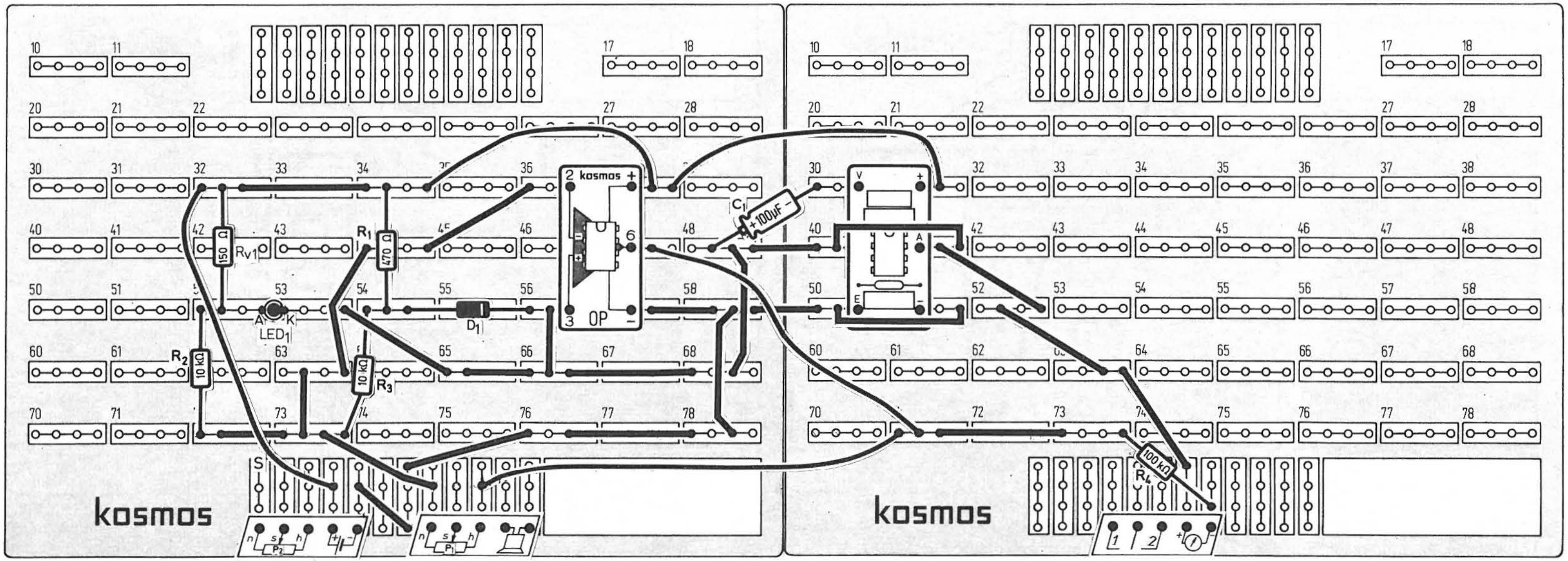
Fig. 249 Noninverting amplifier as impedance converter

that the amplification factor of this circuit is one. It is employed in practice as an "impedance converter" (= resistance converter; high input resistance – low output resistance). A high input resistance means that an extraordinarily low current flows in; a low output resistance means that the amplifier provides a considerable current at its output.

19.5 Calculating electronics - addition and subtraction

We have already spoken about analogue calculations to which the operational amplifier owes its remarkable name. For the sake of completeness we will now try out a few samples of the abilities of the operational amplifier as a calculator.
Let us begin with the simplest case of all; two voltages are to be added, for example the voltage drop across a LED which, as you know, is 1.6V, and the voltage drop across a silicon diode, which you can take to be 0.6V. The result of the addition can be worked out in advance to be 1.6V + 0.6V = 2.2.V – this is why we have taken such a simple example – and this must appear in a measurable form at the output of the operational amplifier adder.
In Fig. 251 the "summands" are placed in little boxes and we assume that 1.6V comes out of the left-hand box and 0.6V out of the right. Since, as you can see at a glance, the operational amplifier

Fig. 250 Construction of circuit 251



is in the inverting mode, you will realize that the result of the addition will be delivered with the opposite sign. This is taken into account in the manner in which the meter is connected in circuit 251 (construction Fig. 250).
Note: The potentiometer P1 is employed as a fixed resistor of 10kΩ in this circuit (the slide is not connected).

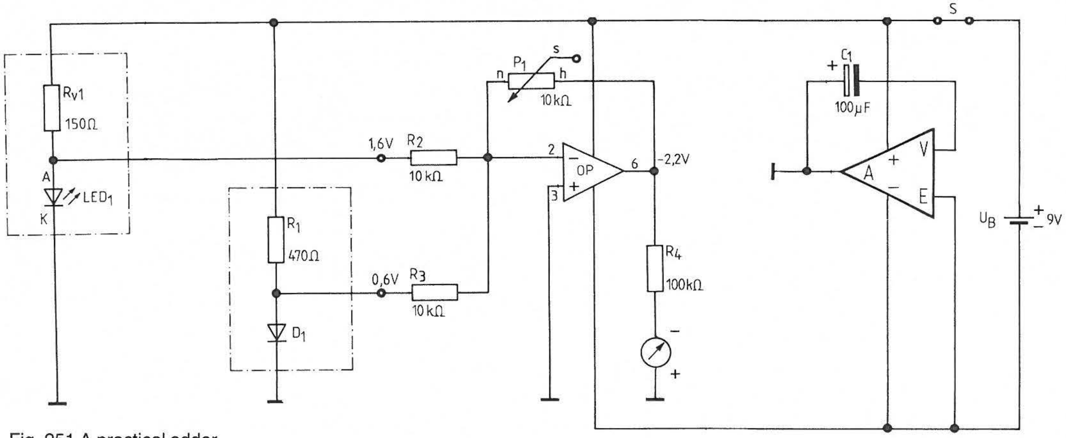

Rv1
150Ω
A
LED1
K
R1
470Ω
D1
1,6V
R2
10kΩ
0,6V
R3
10kΩ
P1
n
h
s
10kΩ
2
3
OP
6
-2,2V
R4
100kΩ
-
+
C1
100µF
+
A
V
E
S
UB
9V

Fig. 251 A practical adder

19.6 The result via three networks

Now at the latest you will come to the conclusion that the simple- looking network rule of Mr. Kirchhoff is an exceedingly useful tool; even those who only partially masters it will have scarcely any difficulty in understanding OP AMP circuits.
Figure 252 shows the basic circuit of an adder. Allowing for the fact that Un is so small that it can be taken as 0, Kirchhoff's network rule gives the following:

1) $-U1 + I1 \cdot R = 0$ or: $U1 = I \cdot R$
   (Network : Ground – E1 – K – Ground)
2) $-U2 + I2 \cdot R = 0$ or: $U2 = I2 \cdot R$
   (Network : Ground – E2 – K – Ground)
3) $-U_o - (I2 + I1) \cdot R = 0$
   or: $-U_o = (I1 + I2) \cdot R$
   (Network : Ground – A – K – Ground)

If 1) and 2) are added then:

$$U1 + U2 = R \cdot (I1 + I2)$$

Substituting this in 3):

(F24) $$U_1 - U_2 = -U_o$$

As we said before the sum is obtained but with a negative sign, which does not bother us because it is the number that we are interested in.

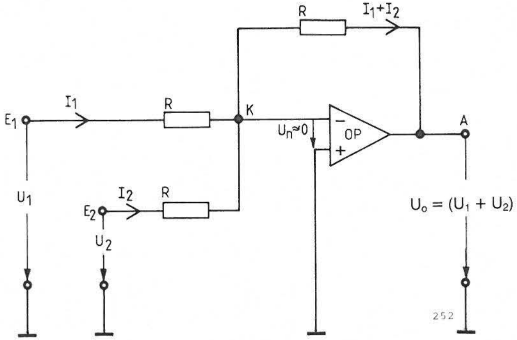

R
I1+I2
E1
I1
R
K
Un≈0
OP
A
U1
E2
I2
R
U2
Uo = (U1 + U2)
252

Fig. 252 The adder in network terms

19.7 Subtracting with Kirchhoff

The method of operation of the subtractor (Fig. 253) is also very easy to understand, when it is noted that here the noninverting input is not grounded, but the voltage difference between the two inputs of the OP AMP can again be taken as zero.

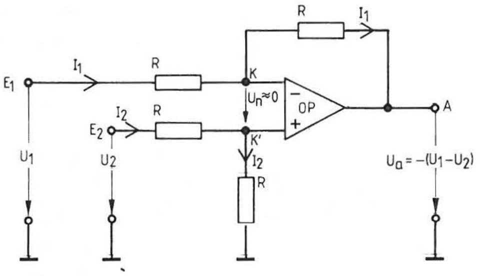


Fig. 253 Subtracter in network terms

Using the Kirchhoff network rule three times we obtain the following relationships:

1) $-U1 + I1 \cdot R + I2 \cdot R = 0$
(Network : Ground – E1 – K – K' – Ground)

2) $-U2 + I2 \cdot R + I2 \cdot R = 0$
(Network : Ground – E2 – K' – Ground)

3) $-U_o - I1 \cdot R + I2 \cdot R = 0$
(Network : Ground – A – K – K' – Ground)

If the three equations are "shuffled" a little then you get:

(F25) $$U_1 - U_2 = -U_o$$

The difference has a negative sign because the OP AMP is inverting.

19.8 The integrator

Integration is an arithmetic operation like multiplication and addition. It is not possible to go into the mathematics nor into the importance of the process, within the confines of this book. However, we will describe what an integrating circuit looks like, how it functions and what it can be used for. Figure 254 shows the circuit of a simple integrator. The feedback to the OP AMP is this time via a capacitor rather than a resistor. This has the result that the output voltage does not stay constant but changes with time even when the input voltage *Ui* remains constant. When *Ui* is small then the increase in *Uo* is small, if, on the other hand, *Ui* is large then *Uo* increases rapidly. *Uo* can naturally never have a value larger than the saturation voltage of the operational amplifier.

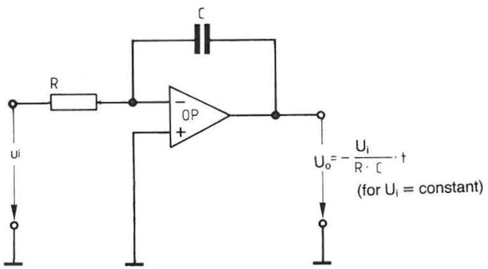


Fig. 254 Diagram of an integrator

The following formula, which has already been calculated out, applies to the case of a constant input voltage:

(F26) $$U_o = \frac{-U_i}{R \cdot C} \cdot t$$

The minus sign indicates that *Uo* "increases" negatively, i.e. it falls if the input voltage is positive.

The mathematically minded will see at once, that the rate of increase of the output voltage depends not only on the prechosen value of *Ui* but also on the capacity *C* and the resistance *R*.

19.9 Breathing acrobatics with electronics

How long can you hold your breath? You can measure the time with an integrator, because when *Ui*, *R* and *C* in Formula 26 are known, then the output voltage *Uo* is directly proportional to the time *t*.

The "breathing apparatus" is constructed according to Fig. 255 (circuit diagram 256). A few remarks concerning its function: Set the control switch to position 2 before every measurement and thus discharge the capacitor, so that the conditions are known (meter reads 0). Now without further ado take a deep breath and turn the knob to position 1 while holding your breath. Keep the control switch in postion 1 until you have to breathe out again. Then you must immediately read the meter; with the components in the circuit one graduation of the meter (that is 1 V output) voltage corresponds (theoretically) to about 10 sec.

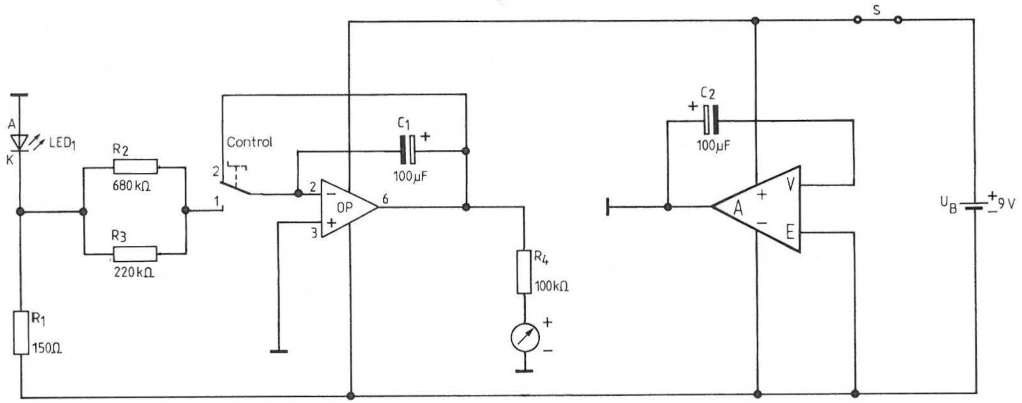
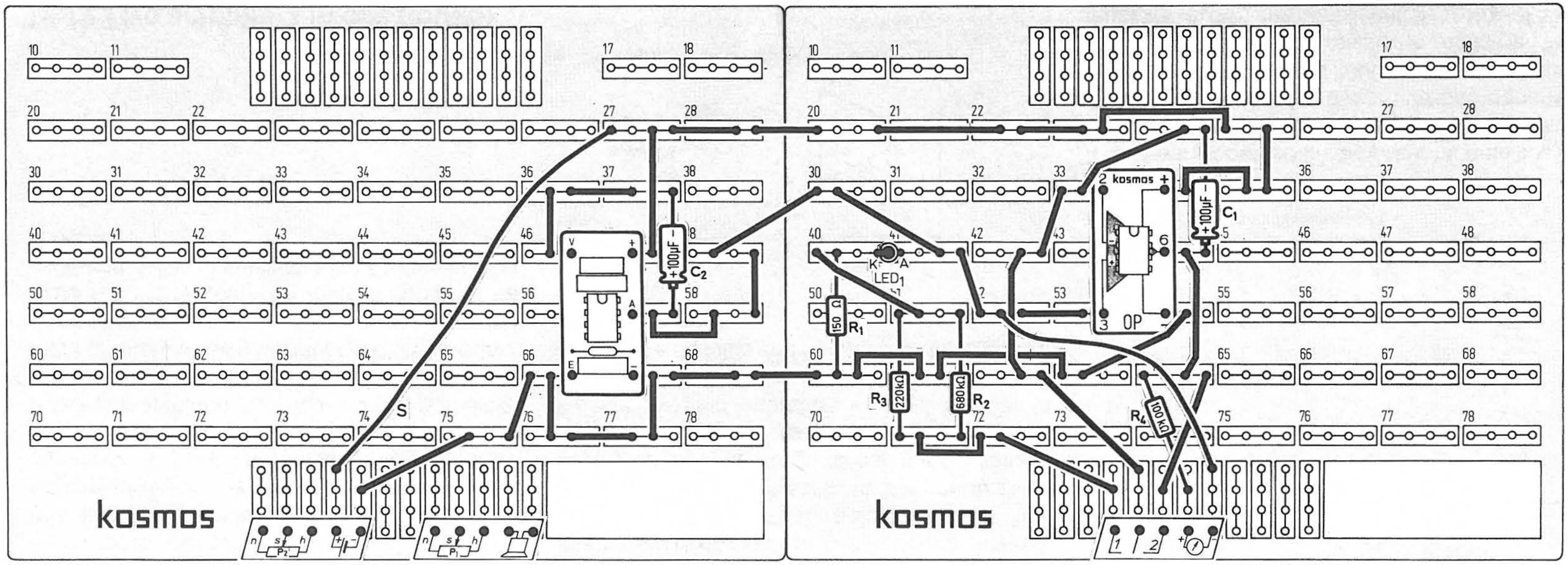

A
K
LED1
R2
680 kΩ
R3
220 kΩ
R1
150Ω
Control
2
1
C1
100µF
OP
2
3
6
R4
100kΩ
C2
100µF
A
V
E
S
UB
9 V

Fig. 256 Circuit for "breathing acrobatics"

Fig. 255 Construction of circuit 256


kosmos
kosmos
LED1
K
A
R1
150 Ω
R2
680 kΩ
R3
220 kΩ
R4
100 kΩ
C1
100µF
C2
100µF
OP
S
P1
P2
1
2

Significantly more has been found in practice; this is a consequence of the tolerances of the components – in particular a 100μF electrolytic capacitor can have a significantly higher capacity than its stated one (up to 50% higher!).
It must be admitted that stopwatches and digital counters, such as are part of the standard equipment of every wristlet watch or pocket calculator nowadays, are much more accurate. But that need not worry you. The main purpose of the experiment was to investigate the behavior of an integrator!

19.10 Two amplifiers in one house: an amplifier module

You can now use your newly acquired knowledge concerning operational amplifiers and take another look at the workings of the amplifier module. Figure 257 shows why it would be wrong to regard the TBA 820 (or equivalent) integrated circuit, that makes up the heart of the amplifier module, as simply an operational amplifier (this is done unforunately in some publications). You can see that this integrated circuit actually consists of an operational amplifier followed by a push-pull amplifier (see Section 22.8 for push-pull amplifiers). In the integrated circuit there is a feedback resistance of 6kΩ connected between the output of the final amplifier and the inverting input of the operational amplifier; hence the feedback is no longer freely adjustable. The final amplifier also has the ability to "symmetrize" the supply voltage, i.e. to go to half supply voltage when the negative battery voltage is supplied to the noninverting operational amplifier input (it requires this property in order to be able to amplify the positive and negative portions of sine waves equally).

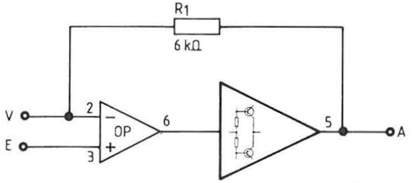


Fig. 257 A peep inside the amplifier module

Figure 258 illustrates, in a somewhat changed form, the simple amplifier with a maximum possible amplification factor of 5000 that you have already used so many times. You can now see that the whole amplifier is driven in the noninverting mode – leave out the capacitor and the amplification factor becomes equal to one; the whole thing then acts as an impedance converter (see Section 19.4). However, with the capacitor it acts as an alternating voltage amplifier, the capacitor sets up a certain resistance towards the alternating current and our amplifier bears a remarkable resemblance to the arrangement in Fig. 246.

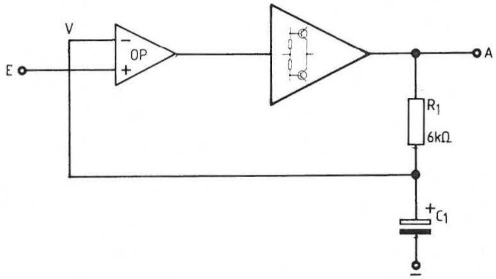


Fig. 258 The input operational amplifier of the amplifier module in noninverting mode.

Thus the trick behind the amplifier module lies in the fact that connection to a capacitor makes the amplification factor for direct currents equal to one, while it can be up to 5000 for alternating currents. The inclusion of a resistor in series with the capacitor allows the amplification factor of the amplifier to be throttled back to whatever value is desired.
You should, after this explanation, look once again at Table 5; you will now find a great deal explicable, which you could only find out previously by experiment.

20. Measurement techniques – part 2

20.1 Electronic surgery

Heart surgeons put in bypasses for arteries that can no longer cope with the full blood supply. We are going to put a bypass on the meter to take the current that would otherwise be too much for it. This is done by putting a resistor in parallel with it as a "bypass", but in electronics it it known as a "shunt". The meter is "shunted" by a parallel resistor as shown in Fig. 259.

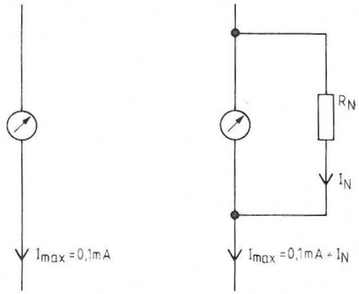


Fig. 259 The meter accepts a maximum current of 100μA, with larger currents a portion has to be shunted round it.

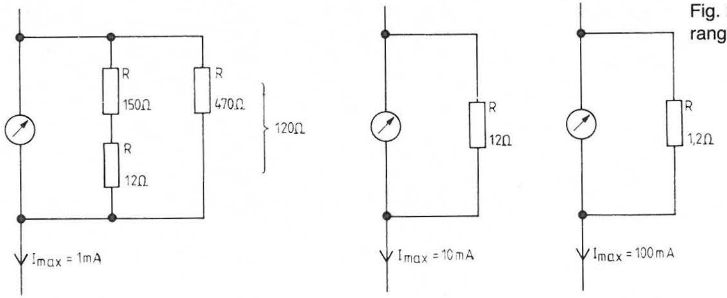


Fig. 260 Shunt resistors for various measurement ranges

How big does this shunt have to be?
The meter cannot carry more than 100μA. If, for example, a current of 100mA is to be measured, then the rest – that is 99.9mA – must flow round it. Figure 260 shows the necessary current branching on the right-hand side.
Current varies as the reciprocal of the resistance (formula F21). The ratio of the shunt current to the meter current is almost exactly 1000:1; so the ratio of the resistances must be 1:1000.
The meter has a resistance of 1200Ω, so the shunt resistance must be 1.2Ω. The shunt resistances for other ranges are calculated by the same method (Fig. 260, left-hand diagram).

20.2 Proper laboratory work - determination of the characteristic curves

Characteristic curves are the A to Z in electronics and they also play an important role in working with transistors. A transistor, in contrast to resistors and diodes, has three connections and its behavior is described by four characteristics:
The collector current *I*c, the base curent *I*b, the collector-emitter voltage *U*ce and the base-emitter voltage *U*be.
It is useful to collect three of these characteristics into a common diagram, but this results in not one line but a whole family of characteristic curves.
You are going to determine the output characteristics, which represent the relationship between the collector current and the collector-emitter voltage at various large base currents. By this means you will see that it is possible to find out the optimal working region (working point) of a transistor by drawing in a boundary output hyperbole and a load line.
Figure 261 shows the construction of the measuring apparatus and Fig. 262 is its circuit diagram. The box surrounded by a broken line with the operational amplifier serves here as a variable voltage source of from 0 to +3V for the transistor

circuit. Since you only possess one meter it has to fulfil two functions one after the other, measurement of current and measurement of voltage drop, at each measurement point.

The recipe for determining characteristic curves is as follows:

1. Remove connector Br, connect meter in its place.
2. Adjust potentiometer P2 until the instrument indicates a base current of 30μA (3 scale graduations). Do not alter P2 any more.
3. Detach meter, replace connector.
4. Connect meter to u and v (polarity!). Adjust P1 so that the meter reads *U*ce = 0.1V (= 1 scale graduation; because the meter is operating in series with a resistance of 10kΩ, full scale deflection represents 1V!). Note *U*ce.
5. Disconnect the meter and reconnect it parallel to the 12Ω resistor – the meter now reads 1mA per scale graduation. Read off and note the value of *I*c. If the meter pointer goes over to the right-hand side then reconnect it parallel to the 1.2Ω resistor and remember that one scale graduation now represents 10mA.
6. Now set *U*ce = 0.2V, *U*ce = 0.3V etc. one after the other with P1 according to point 4. Reconnect the instrument at each value of *U*ce and measure and note the collector current.
7. Read just the base current to 50μA and then to 80μA according to point 1 and then repeat points 1-6 for each new base current level.

Fig. 261 Construction of circuit 262

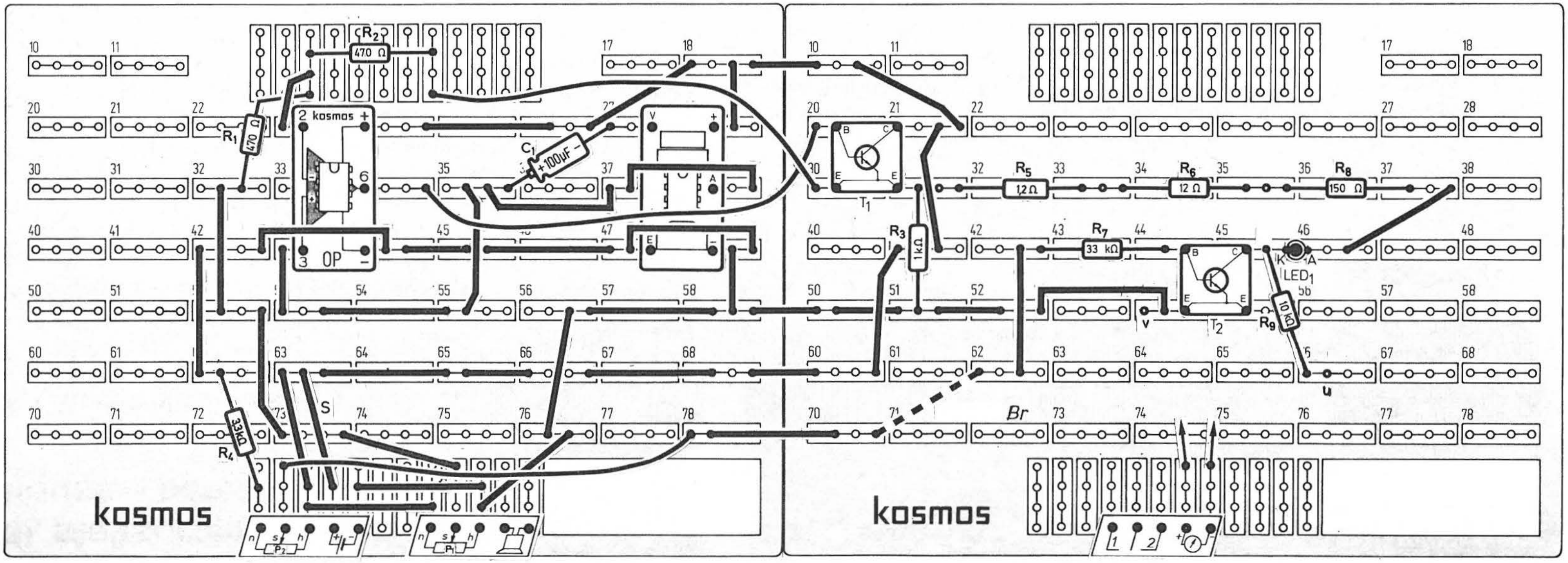
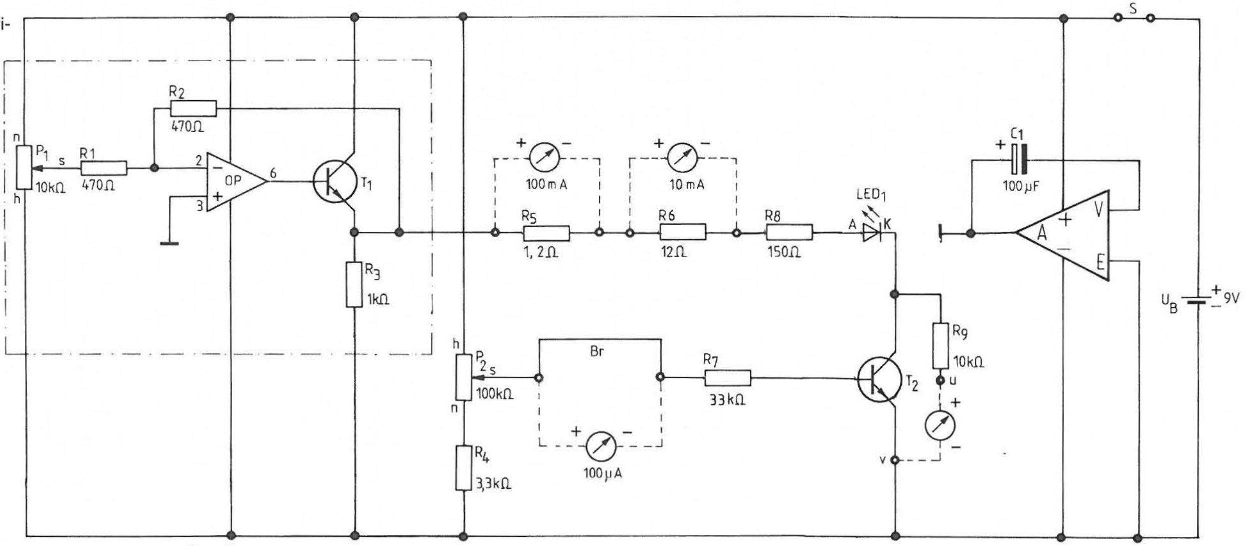
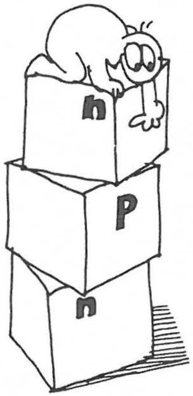
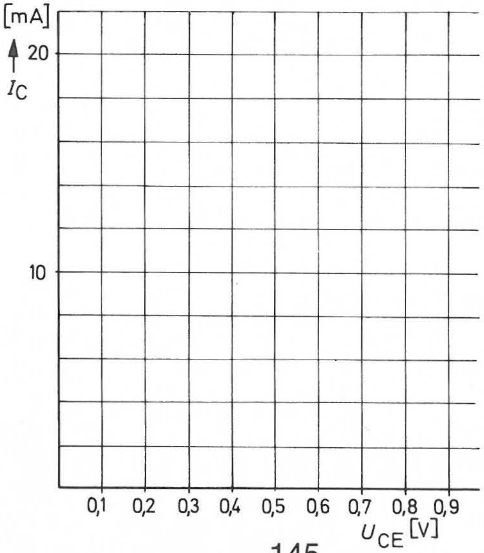


Fig. 262 Circuit for recording transistor characteristic lines


S
R2
470Ω
n
P1
s
R1
10kΩ
470Ω
h
2
OP
6
3
T1
100 mA
10 mA
R5
1,2Ω
R6
12Ω
R8
150Ω
LED1
A
K
C1
100 µF
A
V
E
R3
1kΩ
h
P2 s
100kΩ
n
Br
R7
33kΩ
T2
R9
10kΩ
u
v
100 µA
R4
3,3kΩ
U_B
9V





If you have done everything correctly, you will have obtained a table, whose values you can enter into the empty result form printed alongside; these values will correspond roughly to the family of curves in Fig. 263.

Made it! It took a lot of effort, but it was worth it. Your result could have been taken from the specification sheet of a transistor manufacturer.

U_{CE} [V]	I_B=30µA	I_B=50 µA	I_B=80 µA
	I_C [mA]	I_C [mA]	I_C [mA]
0,1	1,5	3	5
0,2	8	10	16
0,3	11	14	20
0,4	12	15	21
0,5	12	16	–
0,6	12	17	–
0,7	12,5	18	–
0,8	12,5	19	–
0.9	12.7	19	–

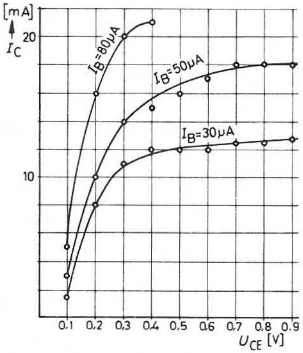


Fig. 263 Self-recorded characteristic lines; your measurement circuit is not particularly suitable for determinations near the zero point.

20.3 On dealing with transistor characteristic curves

A whole lot of important information can be obtained from the output characteristic curves of a transistor.

Figure 264 shows a family of characteristic curves made up of a large number of individual curves. The limiting output hyperbole is also drawn in (225mW according to the manufacturer's specification for BC 238C) and a load line has been drawn in. This line is valid for a collector resistance ("load resistance") of 150Ω. The battery potential was taken as 4.5V in the diagram.

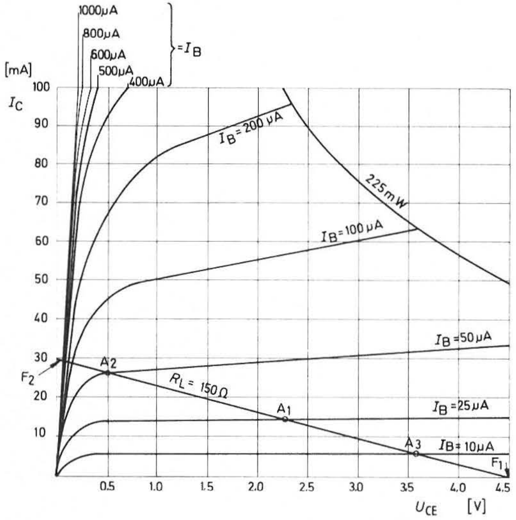


Fig. 264 Family of characteristic lines for BC 238 C

The line is obtained by considering two boundary conditions:

Case 1 The collector current Ic is 0 (transistor nonconducting), there is no voltage drop at the resistor, so the whole of the voltage drop is at the transistor; so Uce = 4.5V. This gives the first point of the load line (point F1).

Case 2 The whole battery voltage is applied to the resistor, the transistor is an ideal conductor, so Uce = 0V. Thus, the maximum possible current of

battery voltage/load resistance = 4.5V/150Ω = 30mA

flows through the load resistance.

This gives the second point (point F2) on the straight line. All values intermediate between F1 and F2 are also possible, since the supply voltage can only divide itself between the voltage drop across the load resistance and the voltage drop across the transistor according to a fixed pattern. The points where the load line intersects the transistor charactertistic are load points that are possible for the transistor.

They reveal what values the collector current, base current and collector-emitter voltage can take up for a given load resistance. For example, at A1, a collector current of 15mA flows and the collector-emitter voltage is 2.25V at a base current of 25μA. The voltage drop across the load resistance is also 2.25V (the supply voltage is devided into two equal portions). If the base current is changed (to A2 or to A3) then the collector current and the collector-emitter current also change.

21. Digital technology - on the road towards the computer

The concepts "analogue" and "digital" have already been mentioned in connection with the operational amplifier and we will now go into the basic difference between the two.

Look at a station clock with second, minute and hour hands; the second hand usually travels at an even speed over the clock dial; it indicates the passage of the seconds without continually stopping; this form of display is known as **analogue**. The minute hand acts differently; each time the second hand completes a revolution the minute hand jumps one minute further; it cannot indicate half or quarter minutes. Such a presentation of a measured value is known as **digital**.

Digital is derived from the Latin word "digitus", which simply means finger in English. You can only count **whole** things on your fingers (for example **1** dollar – **2** dollars – **3** dollars) but not 1.23 – 2.25 – 3.12 dollars.

Take your meter as a second example; it has an analogue display, the pointer moves absolutely regularly over the scale as the voltage is continually increased. If it comes to rest between to graduations then it is necessary to estimate the position of the pointer. The larger the scale and the better the meter, the more precise can be the estimate. A digital meter, on the other hand, delivers us the measured parameter directly in figures; as the potential is continually increased the display jumps endlessly from one digital level to the next.

Intermediate values cannot be read off. Figure 265 illustrates this relationship by means of a very simple example.

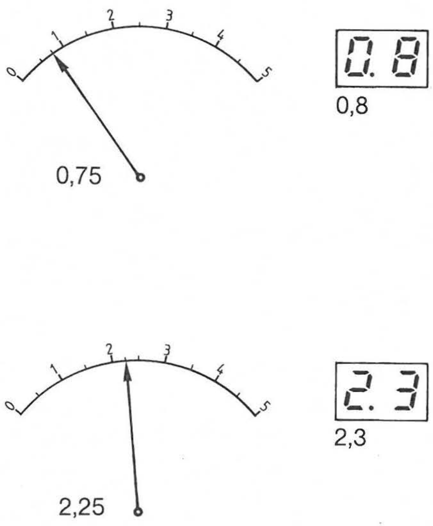


Fig. 265 Analogue and digital displays

21.1 Measurement techniques with advantages and disadvantages

It is not possible to say that either the digital or the analogue displays have absolutely all the advantages in all possible conditions; both have their justification for particular areas of application. Take a look at the (analogue) indicating modulation control of a cassette recorder; in spite of the rapidly changing violin notes we receive useful information concerning whether the recording sensitivity is properly adjusted. A digital display would merely show flickering digits and not provide any digestible information.
Digital instruments are advantageous when the estimation of intermediate settings is difficult and can lead to erroneous readings. But their decisive advantage lies in the fact that the measurement data can be transported over large distances without the introduction of errors and can be fed into a computer for storage and further processing.
These preliminary remarks concerning various types of measurement technique were necessary, in order to make the difference between "analogue" and "digital" plain. We are now going to concentrate on the "logic", on which all modern computers are based.

Anyone who is interested in computers, should certainly take a look at the KOSMOS computer at their hobby and toy dealer's. The knowledge provided in this handbook concerning digital techniques will certainly be of particular assistance if you are going to take up computers.

21.2 Gates – and not only on farms

The basic building block of a computer bears the strange name "gate". A gate processes "logical" values. That does not mean that everything else would be illogical; this is a particular type of logic – the possibility of carrying out the most complex calculations merely by using the values "0" and "1".
This is the basic idea, only two states are allowed, e.g.

voltage or no voltage
current or no current
LED on or LED off
high or low

and one of the states is assigned "1" (voltage present, current flowing, LED on, high) and the other state is assigned "0" (no voltage, current not flowing, LED off, low). Then comes the crazy idea that 1 can represent "true" and 0, on the other hand, "not true". Consequently it is possible to construct a **truth table** for a gate in which all the answers to the question "what happens if" are entered.

21.3 What happens if...

...both left-hand input slides are down (LOW abbreviated to L) in the logic box in Fig. 266? You can see, the LED is on because the right-hand end of the switch platform is up (HIGH abbreviated to H).

...one input slide is pushed up to H? Nothing happens, because the switch platform is prevented from moving by the other slide; the output remains at H.

...if the positions of the two input slides are exchanged, that is one down to L and the other up to H? Again nothing happens, the output remains at H.

...if both input slides are pushed up to H? Now at last something happens, the LED goes out because the switch platform is free and its right-hand side drops down (to L).

All the observations made concerning our logic box, which is a very clear representation of a **NOT AND gate** (this is usually abbreviated to **NAND gate**), are carefully recorded in the table in Fig. 267. Instead of H and L we could equally well have written 1 or 0 or true or untrue. H and L are preferred in electronics because they correspond to H = HIGH = potential difference present, L = LOW = OV or no potential difference present.

21.4 The digital module – quad NAND gates

After so much dry theory we can now return to practice and devote our attention to the digital module; you will be pleased to know that this contains four NAND gates. The truth table given can be checked using the construction in Fig. 270, if you are willing to agree that a depressed contact maker represents HIGH and a contact maker, which it is not depressed, represents LOW. First observe the LED with the contact makers not depressed; then depress only one and then depress only the other and finally depress them both simultaneously.

input slide 1	input slide 2	switch platform
LOW	LOW	HIGH
HIGH	LOW	HIGH
LOW	HIGH	HIGH
HIGH	HIGH	LOW

Fig. 267 Truth table of a NAND gate

Figure 268 shows the circuit diagram symbol for a NAND gate: It has two (logic) inputs, which are labelled E1 and E2, and a logic output labelled A.

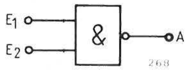


Fig. 268 Circuit diagram symbol for a NAND gate

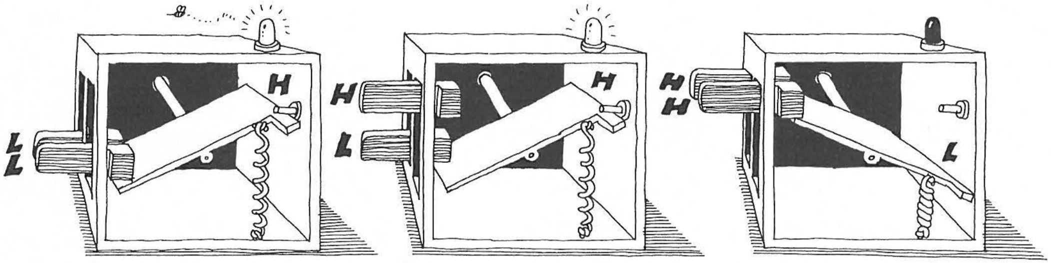


Fig. 266 Logic box for a NAND gate

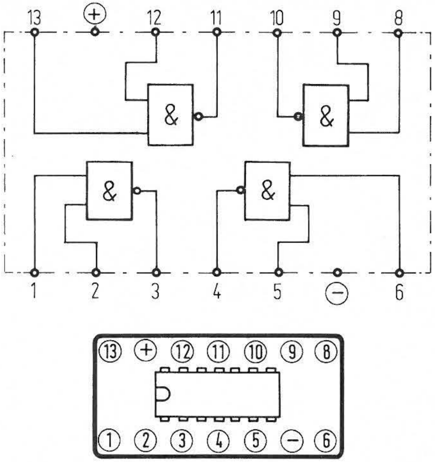

13
+
12
11
10
9
8
&
1
2
3
4
5
−
6
⑬ ⊕ ⑫ ⑪ ⑩ ⑨ ⑧
① ② ③ ④ ⑤ ⊖ ⑥

Fig. 269 The KOSMOS digital module

Take care! Incorrect connection (+ and − reversed) of the digital module will lead to its immediate destruction.

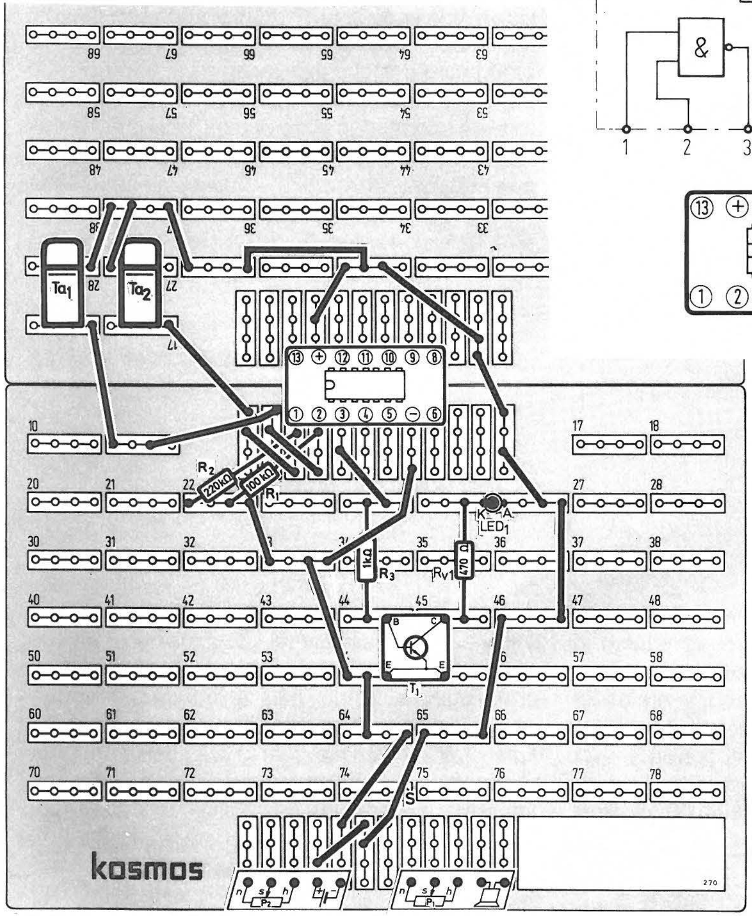

Ta1
Ta2
R2
220kΩ
100kΩ
R1
K
A
LED1
1kΩ
R3
470 Ω
Rv1
B
C
E
T1
S
P2
P1
kosmos
270

Fig. 270 Construction of circuit 271

Note: For the sake of clarity the circuit diagrams with the digital module omit the connections to the batteries. These are, of course, included in the corresponding constructional diagrams.

Circuit diagram 271 shows how the inputs are set up for the H and L states; each input is connected to negative by means of a resistor, i.e. when the contact maker is not depressed it receives 0V (thus it is at "low"). Depressing a contact maker causes the appropriate input to be connected directly to positive (it is then at "high").

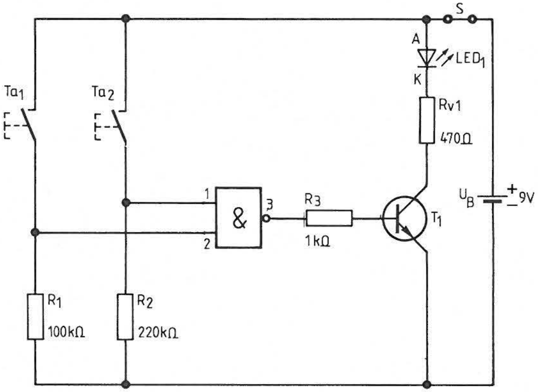

S
A
LED1
K
Rv1
470Ω
Ta1
Ta2
1
2
&
3
R3
1kΩ
T1
UB
+
9V
R1
100kΩ
R2
220kΩ

Fig. 271 Test circuit for a NAND gate

What is the transistor for?

Your digital module was manufactured using modern CMOS technology (CMOS – pronounced seamoss – is the abbreviation for **C**omplementary **M**etal **O**xide **S**ilicon. This is a special process for manufacturing semiconductor components, which is very different from the one used for normal transistors, or for your OP AMP or amplifier module.) Electronic components manufactured using CMOS technology are particularly economical in their current consumption. A fraction of a milliamp at their inputs is sufficient to control them. However, the output is also miserly so that a current amplifier always has to be included so as to be able to drive a LED.

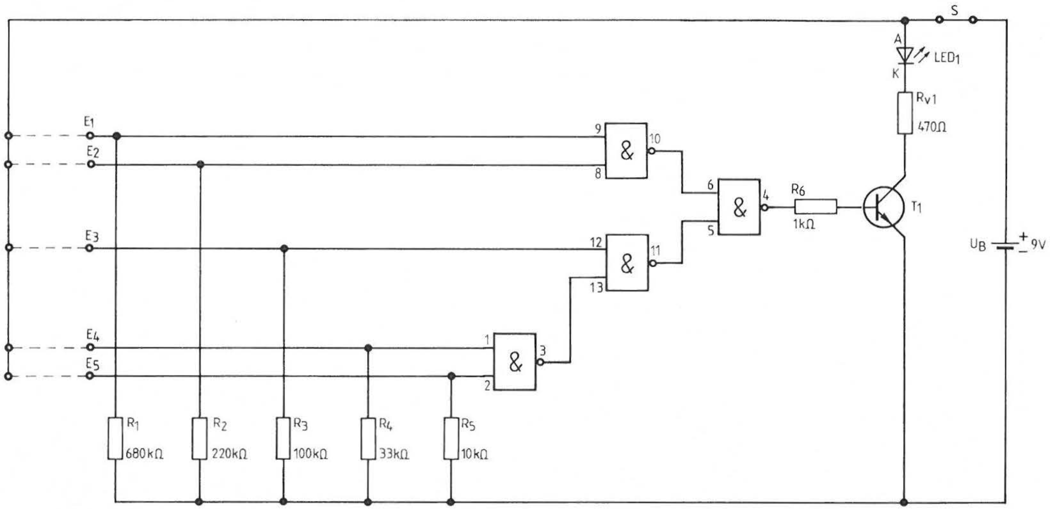
21.5 A practical example with NAND gates

How do you start anything with such a gate in practice?
Imagine the following – A streetcar with front and back doors, that have to be supervised by the driver. A contact is fitted to each door and this is closed when the door is closed and open when the door is open. The driver can check if both doors are properly closed before he starts, simply by looking at a control lamp. The lamp is only **not** lit when contact 1 **and** contact 2 are both closed. Closing just one contact is not sufficient to put the lamp out. Here you recognize the logic of the NAND circuit; two conditions have to be fulfilled (true), in order that a thing shall **not** happen.

21.6 A digital puzzle

Now let us relax a little and make a puzzle game with NAND gates. Figure 273 shows a dice circuit with 4 gates; five inputs are available – which have we to put to high and which to low in order to make the output go to high?
The solution can be easily found by a few minutes of mental calculation; for the practically inclined we suggest the construction in Fig. 272, with whose aid it is possible to check out the 32 (!) possibilities. The broken lines indicate the places where wire connectors must be inserted in order to put the appropriate input to high. So an inserted wire connector means an input at high and a noninserted wire connector means an input at low (this behavior is brought about once again by resistors that are connected between the inputs and negative – they are known as **pull down resistors**.) Incidentally there are 17 combinations of inputs, where the output goes to high.

Fig. 273 A digital puzzle



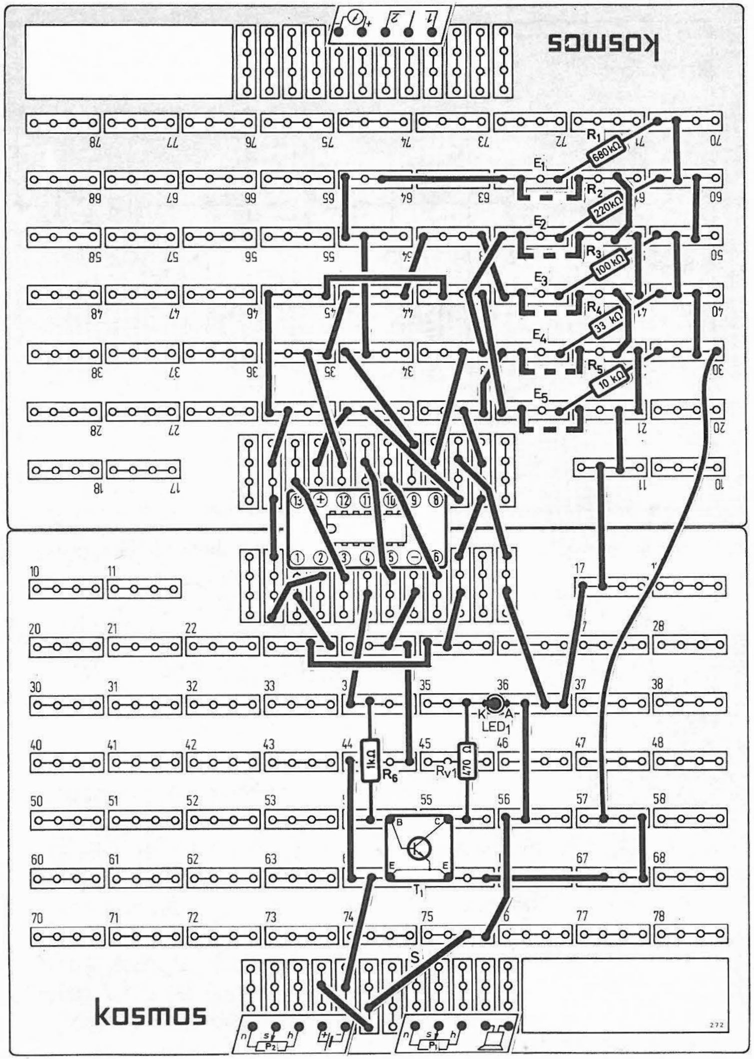


Fig. 272 Construction of circuit 273

21.7 From digital puzzle to code lock

Such a play circuit naturally has its useful aspects. It is excellently suitable for ensuring the security of a safe or of a room or closet door. For example, the KOSMOS mains switch X (see end of book) is inserted into the circuit instead of the LED and its protective resistor; its switch contact is then connected to an electrical door opener. The door opener only operates when the correct combination of highs and lows is chosen at the input.

Suggestion for experiment:

Should an unauthorized person "crack" the code, it is very easy to reconstruct the circuit for other combinations of highs and lows. There are a large number of connection possibilities...

21.8 A gate as an inverter

The concept of "inversion" is known to you from transistor and OP AMP circuits. The gate inverter performs "logical" inversion; a "1" at the input produces a "0" at the output and a "0" at the input produces a "1" at the output (or – a high goes to low and a low goes to high).

If both inputs of a NAND gate are connected together and employed as a **common** input then there you have your inverter. Figure 274 shows on the left that the inverter has its own circuit diagram symbol (components containing ready-made inverters with one input and one output are available commercially), however we will employ the right-hand representation in what follows, so that you do not forget that your inverters are made up of NAND gates.

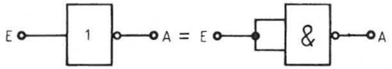


Fig. 274 Circuit diagram symbol for an inverter

Fig. 276 A chain of three inverters

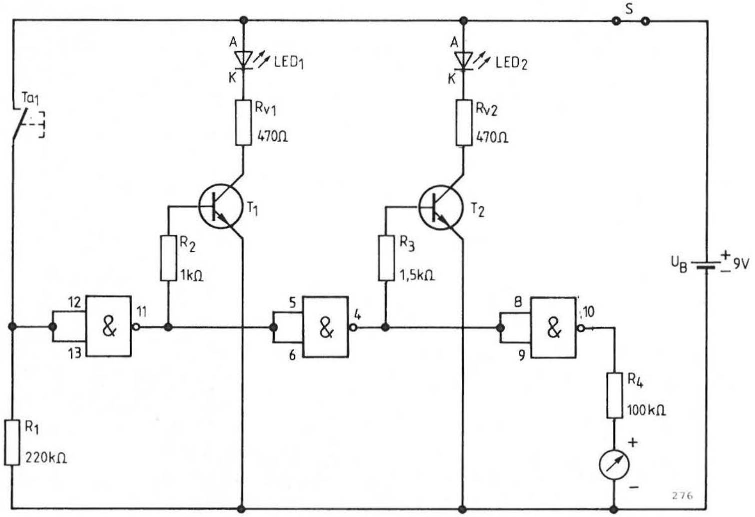
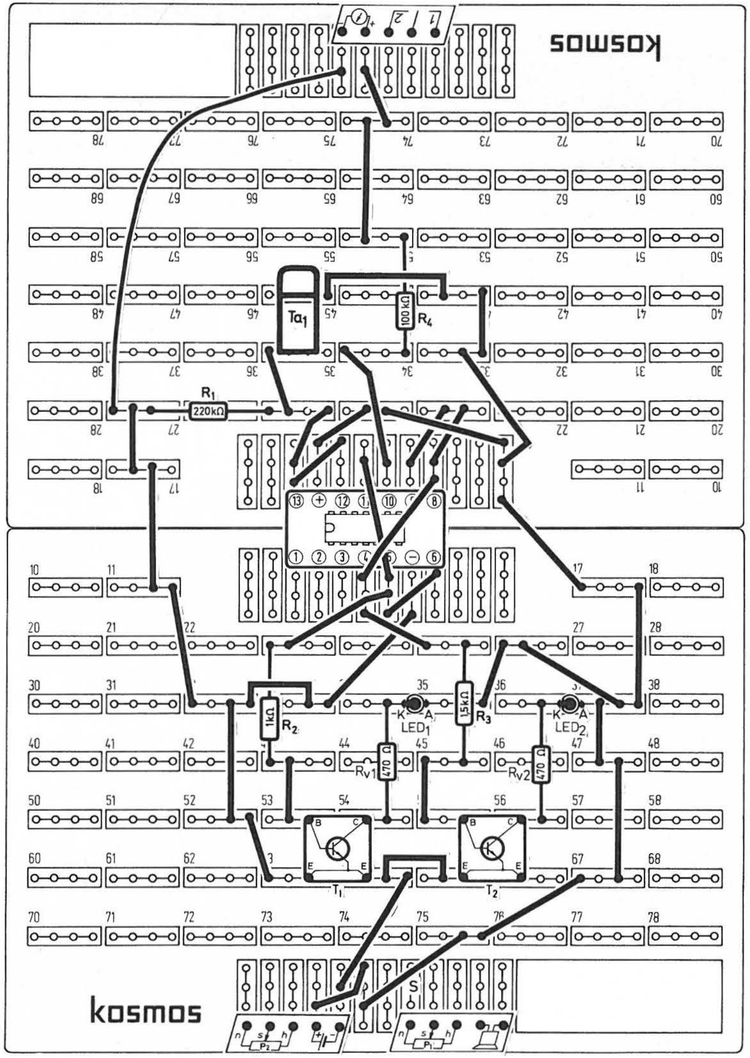

S
A
LED1
K
A
LED2
K
Ta1
Rv1
470Ω
Rv2
470Ω
T1
T2
R2
1kΩ
R3
1,5kΩ
12
13
11
&
5
6
4
&
8
9
10
&
UB
+
9V
R4
100kΩ
+
−
R1
220kΩ
276

Fig. 275 Construction of circuit 276


kosmos
Ta1
100kΩ
R4
R1
220kΩ
1kΩ
R2
1,5kΩ
R3
K
A
LED1
K
A
LED2
470Ω
Rv1
470Ω
Rv2
T1
T2
B
C
E
S
P1
P2
kosmos

You can convince yourself of the inversion function with your own eyes if you assemble the string of three inverters in Fig. 275. A "1" at the input (contact maker depressed) produces a "0" at the output of the first inverter (LED1 out) and a "1" at the second output (LED2 lit) and a "0" once again at the third output (meter reads 0V). Exactly the opposite states are obtained when the contact maker is released. Figure 276 shows the corresponding circuit diagram.

21.9 AND gates by logic conversion

Inverters turn out to be extremely useful if you are dissatisfied with the logic of the NAND gate. That can be the case in this problem for instance: A heavy press is employed for manufacturing automobile bodies and is operated by one worker. In order to avoid accidents the press can only descend when two levers at the side of the machine are operated, one with the left hand and the other with the right, after the material has been inserted.

The logic of a NAND gate does not work here; an event is to take place here when one condition (pressing the left-hand lever) **and** another condition (pressing the right-hand lever) are both fulfilled. An AND gate provides for this combination. It can be seen at once that the AND function is the logical opposite of the NAND function and you can also see the utility of an inverter. A NAND gate followed by an inverter yields an **AND gate**. Its truth table is given in Fig. 277 and its circuit symbol in Fig. 278. In order to make your understanding more complete Fig. 279 shows the familiar logic box, but this time for an AND gate.

E_1	E_2	A
L	L	L
L	H	L
H	L	L
H	H	H

Fig. 277 Truth table of an AND gate

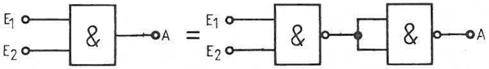


Fig. 278 Circuit diagram symbols for AND gates

But now at this point we want to insert a short comment and also to answer a question, that it must be acknowledged is warrented; why was the AND gate not presented first (as it usually is in textbooks because its logic seems, at first sight, more plausible) and then the NAND gate developed from it? Now we deliberately chose a component containing NAND gates for this kit, because it can be employed to build up other types of gates. And it seemed sensible to us to start with a "simple" gate and not with a "composite gate" made up from others.
End of comment -

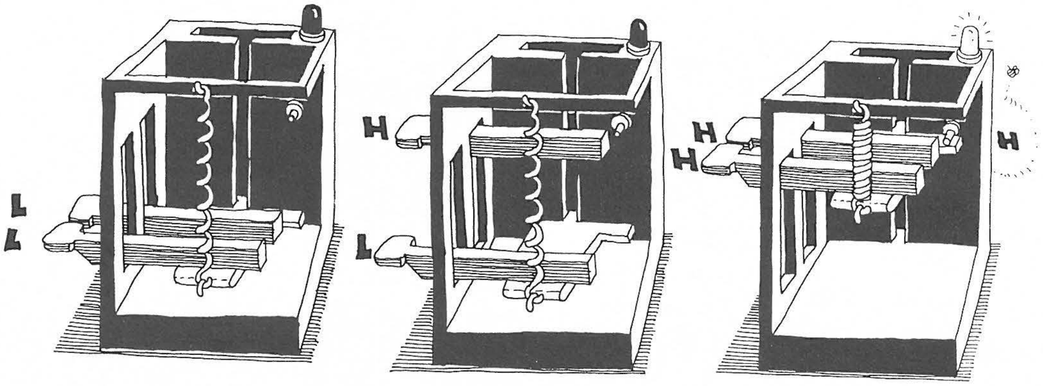


Fig. 279 Logic box of an AND gate

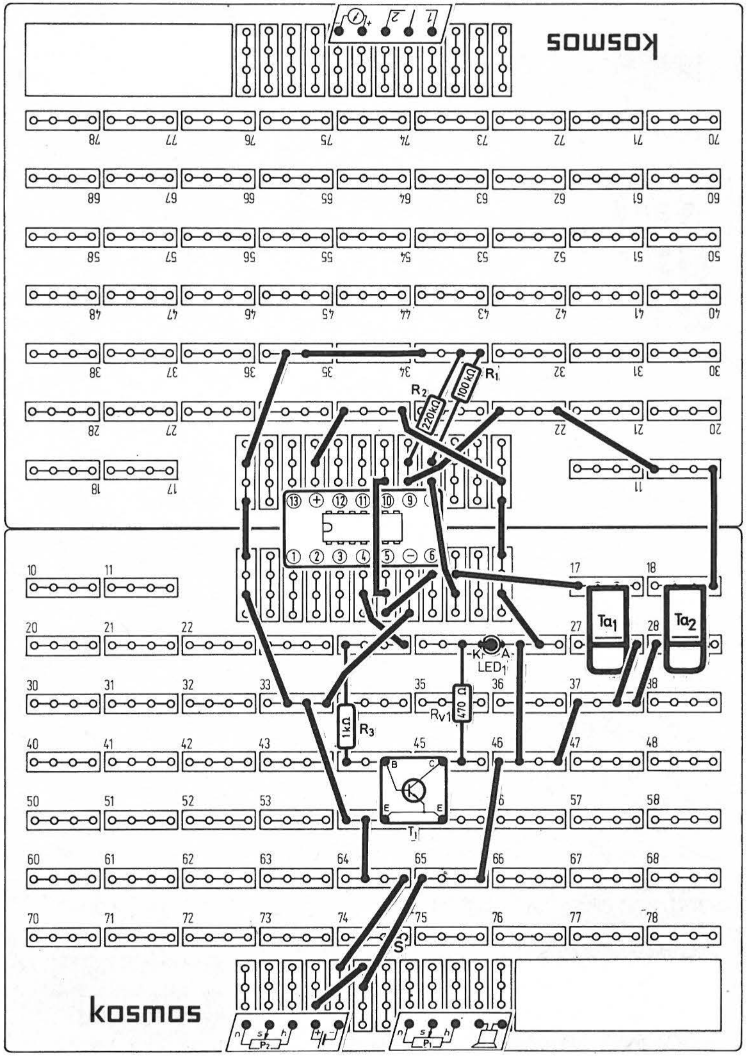

kosmos
R₁
100 kΩ
R₂
220 kΩ
Ta₁
Ta₂
LED₁
K
A
Rv₁
470 Ω
R₃
1 kΩ
B
C
E
T₁
S
P₁
P₂

Fig. 280 Construction of circuit 281

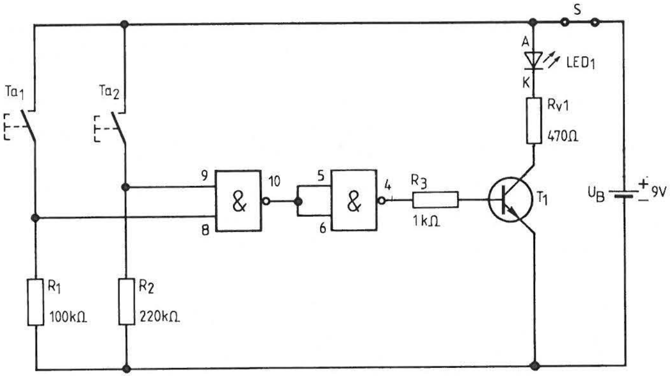

S
A
LED1
K
Rv1
470Ω
Ta1
Ta2
9
10
5
4
R3
&
&
8
6
1kΩ
T1
UB
9V
R1
100kΩ
R2
220kΩ

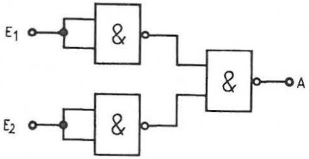
Fig. 281 Test circuit for an AND gate

You should certainly try out the function of an AND gate according to constructional diagram 280 (circuit diagram 281). Here again the rule applies; contact maker not pressed = logical "0" at input, contact maker pressed = logical "1" at input.

21.10 Little puzzles

The following exercises have been thought up, not exactly as a thrilling party game, but perhaps as a useful means of bringing the little grey cells into action. Four different gate connections are given in Figs. 282 to 285. Who can enter the correct values in the accompanying truth tables?

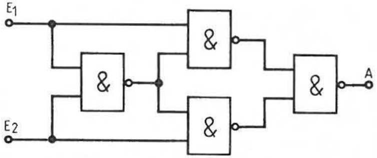
Note 1: Slow-thinking but practically gifted people should build the circuits and find the solutions by trial and error.



E_1	E_2	A
L	L	
L	H	
H	L	
H	H	

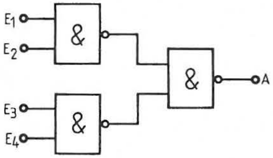
Fig. 282 Exercise 1: What does the truth table look like?

Note 2: If you are being driven mad you can look up the solutions. They are printed at the end of Section 21!



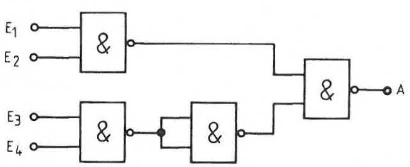
E_1	E_2	A
L	L	
L	H	
H	L	
H	H	

Fig. 283 Exercise 2: What does the truth table look like?



E_1	E_2	E_3	E_4	A
L	L	L	L	
L	L	L	H	
L	L	H	L	
L	L	H	H	
L	H	L	L	
L	H	L	H	
L	H	H	L	
L	H	H	H	
H	L	L	L	
H	L	L	H	
H	L	H	L	
H	L	H	H	
H	H	L	L	
H	H	L	H	
H	H	H	L	
H	H	H	H	

Fig. 284 Exercise 3: What does the truth table look like?



E1	E2	E3	E4	A
L	L	L	L	
L	L	L	H	
L	L	H	L	
L	L	H	H	
L	H	L	L	
L	H	L	H	
L	H	H	L	
L	H	H	H	
H	L	L	L	
H	L	L	H	
H	L	H	L	
H	L	H	H	
H	H	L	L	
H	H	L	H	
H	H	H	L	
H	H	H	H	

Fig. 285 Exercise 4: What does the truth table look like?

21.11 Gates for every purpose

Those of you who have found it pretty dumb just getting a logical "1" or a logical "0" as a result, will be astonished at the circuits that follow, because there are almost endless possibilities for the application of NAND gates: oscillators, flip-flops, monoflops, multiplexers, voltage doublers... our gates are up to everything!

21.12 How to gate a flip-flop

Let us go back to the famous computer element, the flip-flop storage component – but this time we are going to come a great deal closer to actual computer practice. The memories of computers are indeed made up of gates, however a specialized computer component the size of our quad NAND gate nowadays contains hundreds, or even thousands of gate flip- flops.
In the case of a transistor flip-flop, you always connected the collector (output) of one transistor with the base (input) of the other. If you cannot remember you can always look at Fig. 81 again. A gate flip-flop is arranged in just the same manner as a transistor one (circuit diagram 287) and because of this there is no need for any longwinded explanations. The remaining inputs are connected to contact makers which are labelled S (= "**S**et") and R ("**R**eset), in each case via an inverter. Pressing down contact maker S puts the flip-flop into one state and the use of the other contact maker returns the flip-flop to the original state (construction 286). Such a flip-flop is known as a **RS flip-flop**.

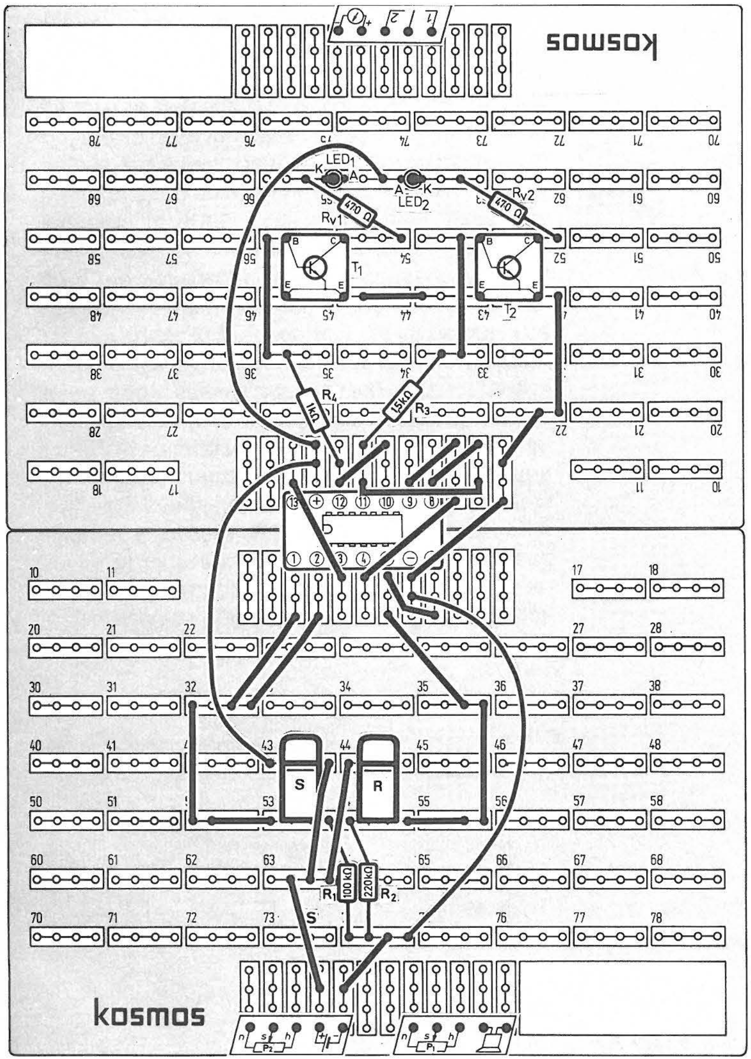

kosmos
LED1
K
A
LED2
Rv1
470 Ω
Rv2
470 Ω
T1
T2
B
C
E
R4
1kΩ
15kΩ
R3
S
R
R1
100 kΩ
220 kΩ
R2
kosmos

Fig. 286 Construction of circuit 287

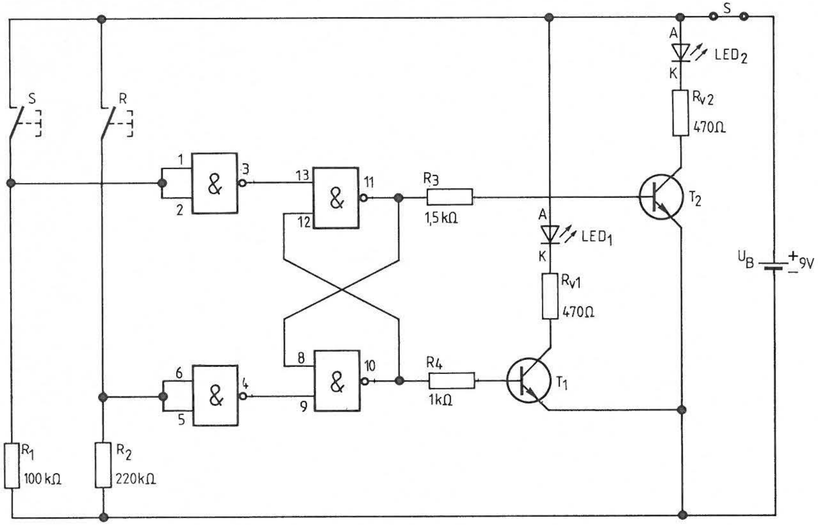

S
R
S
A
K
LED2
Rv2
470Ω
1
2
3
&
13
12
11
&
R3
1,5 kΩ
T2
A
K
LED1
Rv1
470Ω
UB
+9V
6
5
4
&
8
9
10
&
R4
1kΩ
T1
R1
100 kΩ
R2
220 kΩ

Fig. 287 Flip-flop from gates

21.13 Gates produce notes

A note generator can also be operated “logically“. All that you need are two inverters, two resistors and naturally a capacitor (circuit diagram 289). Just to try it out (constructional diagram Fig. 288) you only need the very simplest amplifier (transistor T1 and earphone). Later you can use your amplifier module for real “sound“.

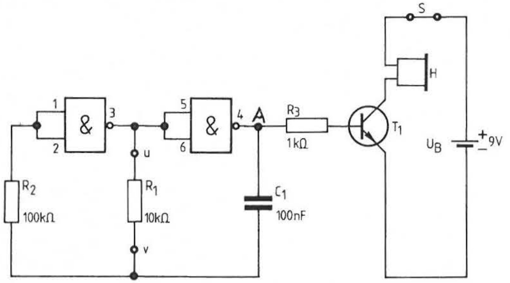
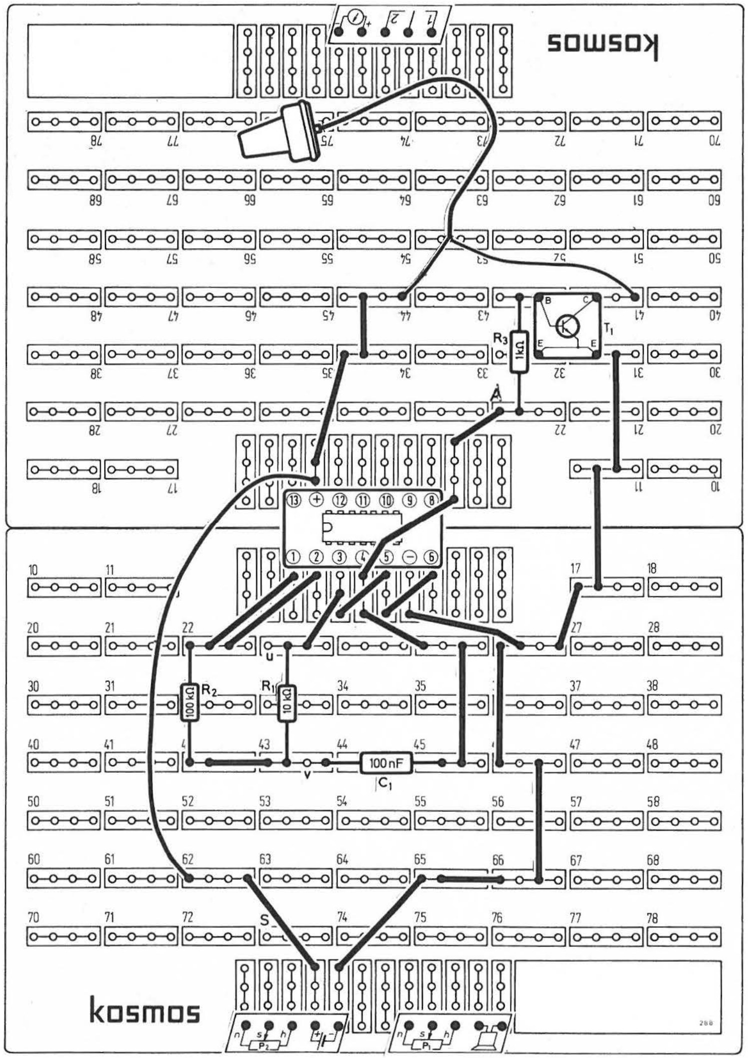
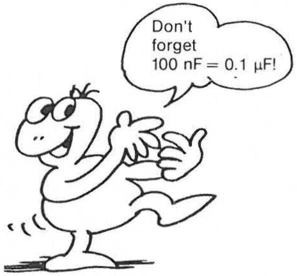

S
H
1
2
3
&
5
6
4
A
R3
1kΩ
T1
UB
+9V
u
R2
100kΩ
R1
10kΩ
C1
100nF
v

Fig. 289 Note production with gates

Fig. 288 Construction of circuit 289

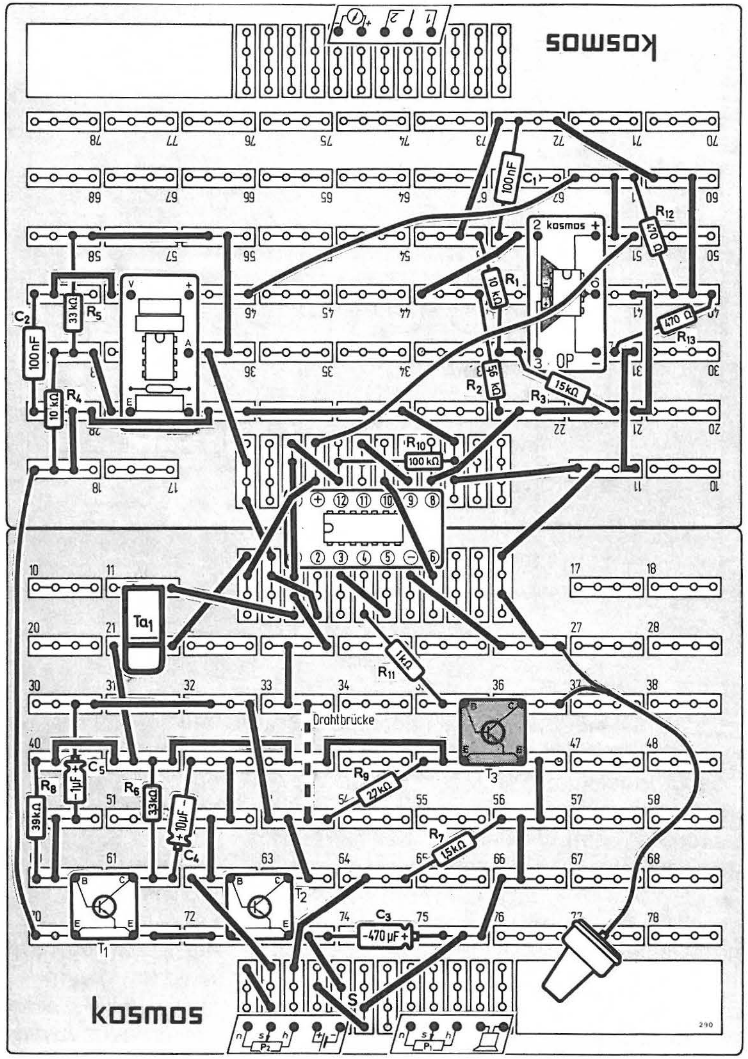

kosmos
R3
1kΩ
T1
B
C
E
A
R2
100 kΩ
R1
10 kΩ
u
v
100nF
C1
S
P2
P1
kosmos

Let us assume that, at the moment the supply voltage is turned on, the output of the left-hand inverter is at high and the output of the right-hand inverter is accordingly at low. The capacitor is naturally completely uncharged at first, but it is then slowly charged via resistor *R*1. When the charging voltage reaches a certain value the left-hand inverter "perceives" this as a logical "1" at its input, and – since it behaves logically – it inverts it to a logical "0" at its output and causes the right-hand inverter to produce a "1" at its output. The capacitor is then charged in the opposite direction; the voltage at its lower connection sinks, until it reaches a value that means an "0" for the left-hand inverter. Thus the original state has been reached once more and the whole process begins yet again. Suggestions for experiments: Set the value of the capacitor at 6.8nF. In order to be able to adjust the note continuously, replace *R*1 by potentiometer P2 or by potentiometer P1 (only connect the slide and one outer connection in each case).


Don't forget 100 nF = 0.1 µF!

The amplifier module can be connected in at point A via a 0.1μF capacitor (via the capacitor to input E; from there 5.6kΩ to negative; input V via a 10μF capacitor to negative; output via 10μF and loudspeaker to negative).
Remove the potentiometer or resistor and attach two long wires, one at u and the other at v. If you get hold of these wires more or less firmly with your hand or experiment with dry or somewhat moist hands (principle of the lie detector) then the note changes. Try out all possible value combinations for *R*1 and *C*1.

Fig. 290 Construction of circuit 291



kosmos
C1
100nF
R12
470 Ω
2 kosmos +
R1
10 kΩ
R13
470 Ω
OP
R2
56 kΩ
R3
15kΩ
V
A
E
C2
100nF
R5
33 kΩ
R4
10 kΩ
R10
100 kΩ
Ta1
R11
1kΩ
Drahtbrücke
T3
R9
27kΩ
R7
15kΩ
C5
1µF
R8
39kΩ
R6
33kΩ
C4
10µF
T1
T2
C3
470 µF
S
P2
P1
kosmos
290

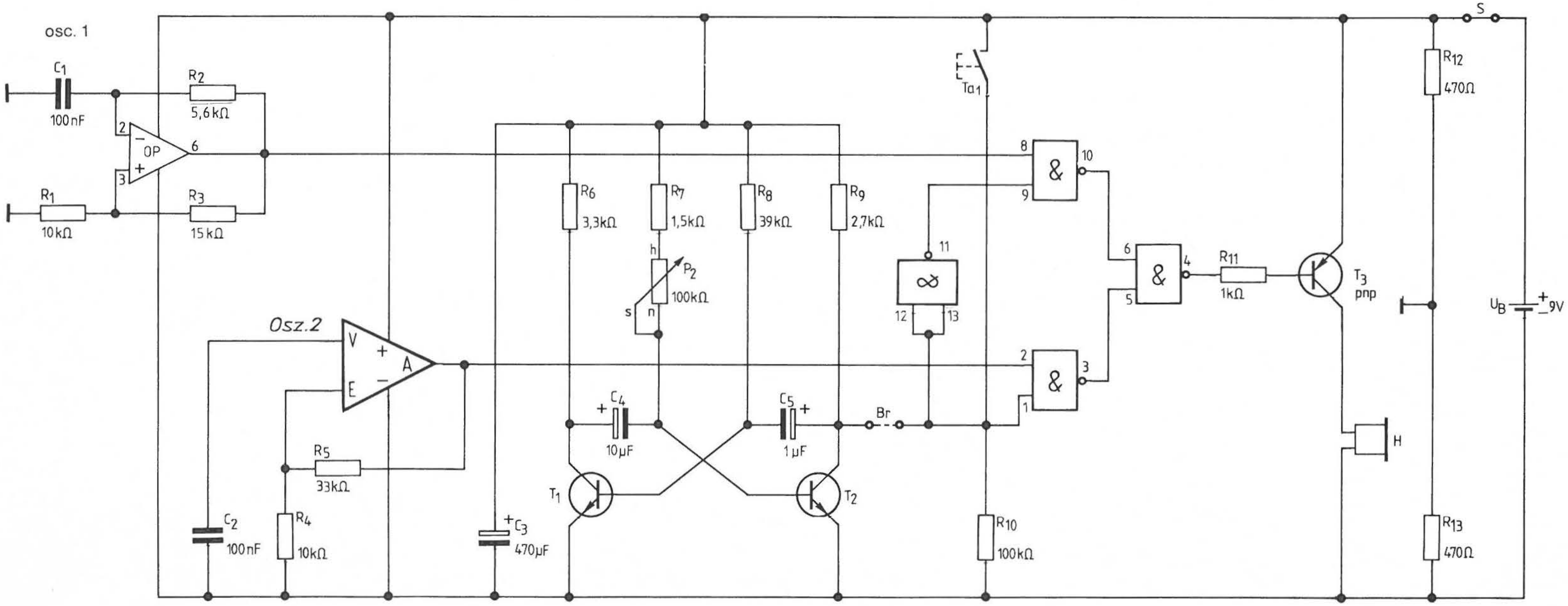
21.14 Long leads for many

If you have carried out an intercontinental telephone conversation you are sure to remember that the line sometimes seemed dead, that the conversation was cut off. And suddenly the caller at the other end was there again, as if nothing had happened. In fact a vast number of electronic events have occurred during the interruption. Since intercontinental lines are expensive – very expensive! – they have to be employed as intensively as possible. If a short pause (e.g. while thinking) occurs during a conversation, then the exceedingly sensitive electronics reacts immediately and allots the line to another pair of callers who are chatting furiously at that moment. When the pause in the conversation ends the electronics provides a vacant line – e.g. from a pair of callers who are pausing for breath at that moment. In this way a few lines can be employed simultaneously by many people – naturally without your hearing what the other pairs of callers are saying. Such continuous switching backwards and forwards is known as **multiplexing**. A whole range of different types of multiplexing are known, one of them is called the **frequency multiplexing process** whereby two frequencies are transmitted simultaneously over the same line, by switching one frequency and then the other frequency onto the line in rapid succession. At the reception site the two frequencies (each of which can transport a certain content of information) have to be separated from each other (**demultiplexing**).

You can build a multiplexer for two frequencies according to constructional diagram 290. The wire connector Br is **not** connected at first. If all the connections are made correctly and the battery is attached then a note will be heard. It comes from oscillator 1 (circuit diagram 291). You can now switch to the note from oscillator 2 by depressing the contact maker; the higher note of oscillator 2 now comes on the line (i.e. in your earphone).

Note: This is not a case of a note generator producing different frequencies (e.g. by changing the values of the resistors or capacitors), but rather the frequencies of two completely independent oscillators (note generators) have been switched through a digital multiplexer.

Fig. 291 Multiplexer


osc. 1
C1
100nF
R2
5,6kΩ
2
–
OP
+
3
6
R1
10kΩ
R3
15kΩ
Osz.2
V
+
A
E
–
R5
33kΩ
C2
100nF
R4
10kΩ
+C3
470µF
R6
3,3kΩ
R7
1,5kΩ
h
P2
100kΩ
s
n
R8
39kΩ
R9
2,7kΩ
C4
10µF
C5
1µF
T1
T2
Br
Ta1
8
9
&
10
11
12
13
2
1
&
3
6
5
&
4
R11
1kΩ
T3
pnp
H
S
R12
470Ω
R13
470Ω
UB
+
9V

We can go a stage further and automate the switching process. To do this plug in the wire connector Br thus making connection to a third oscillator, which produces the switching frequency. The chirping you now hear in the earphone is made by the rapidly alternating sequence of the two frequencies. Figure 292 shows this behavior in a voltage time diagram.

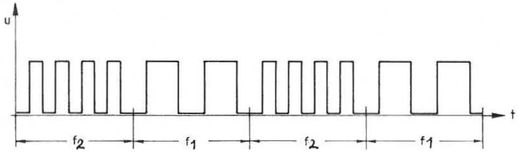


Fig. 292 Voltage-time diagram of the multiplexed frequencies

Everyone can clarify the logical behavior of the multiplex circuit made up of the four gate components, by asking the famous question "what happens if…"; the rest of the layout is made up of oscillator circuits that are completely familiar to you. A word concerning the operational amplifier; here, by way of an exception, the midpoint ground is produced by means of two 470Ω resistors, which act as voltage dividers and produce exactly half the battery voltage at their midpoint.

21.15 18 volts from a normal 9V battery

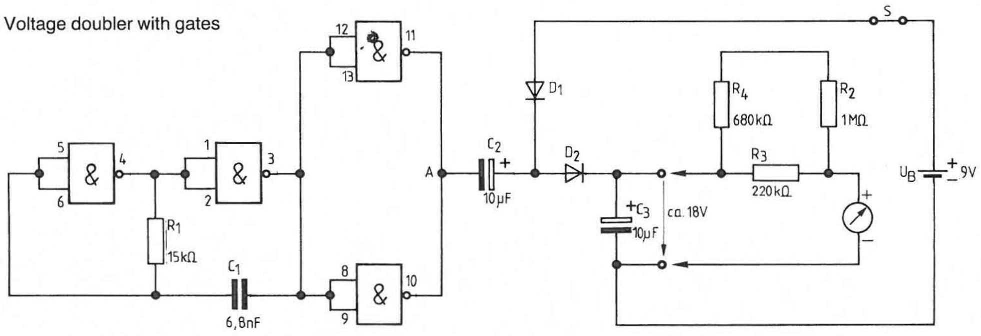
It is not all that infrequent in electronics that a particular circuit only operates satisfactorily at a higher voltage (you will meet such a circuit in the next section). The simplest solution of course is to add another battery; but that shows lack of imagination and runs away with pocket money in the long run. Clever engineers have an electronic answer and construct a circuit that can double a (direct current) voltage. The principle of voltage doubling is quite simple; electrons (charge) are continually pumped into a capacitor and their way back is blocked by means of a diode. At any given capacity the voltage across a capacitor is proportional to the amount of charge Q. Expressed as a formula:-

Charge = capacity times voltage

(F27) $Q = C \cdot U$ or : $U = \frac{1}{C} \cdot Q$

This relationship is very illuminating, for the pressure in a tire is proportional to the amount of air you pump into it.
However, in contrast to a tire you do not need to have any anxiety that a capacitor will burst because you pump too many electrons into it (unless you exceed the allowed voltage across the capacitor); neither the capacitor nor the diode is completely "airtight" so that after the pumping has been going on for some time an equilibrium voltage is achieved.
Figure 294 shows on its left-hand side two inverters operating as astable multivibrators, they produce a frequency of ca. 8kHz. The two following

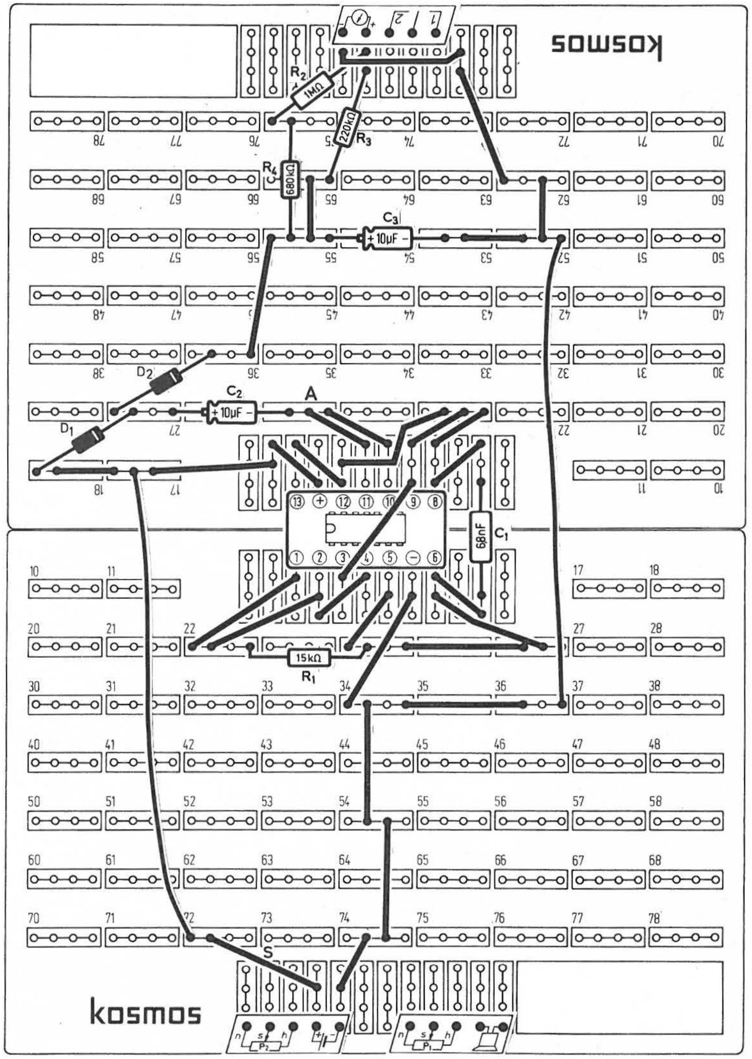
Fig. 294 Voltage doubler with gates



parallel connected inverters act as "buffers"; on the one hand, because of their high input resistance they guarantee that virtually no current is drawn from the multivibrator circuit (which would bring its function into question) and, on the other hand, their parallel connected outputs are able, working together, to provide a few milliamperes for the following capacitor diode circuit.
So far – so good; now look at the right-hand half of the circuit as a whole. The square wave voltage produced by the multivibrator arrives at point A – the fact that it has been inverted is of no importance. If diode *D*1 were not included an a.c. voltage would have been available after capacitor *C*2 (compare Figs. 77 and 78!), this diode short circuits the negative half-wafe and leads wave and leads the positive half to diode D2 which is conducting in this direction. Capacitor *C*3 is thus pumped full by the method described above and reaches up to 18V without any difficulties – when the battery supplying the circuit is fresh. You can measure it with the meter (Fig. 293), but you must remember that the meter resistance chosen here (220kΩ in parallel to 1MΩ and 680kΩ in series, gives ca. 200kΩ in all) means that the full-scale deflection of the meter is now 20V, so that all the readings have to be multiplied by 2 (example: reading 9 scale deflections – measured voltage is 18V).

Incidentally circuits of this type are employed in television sets in order to produces the high voltages necessary for the video tubes.

Fig. 293 Construction of circuit 294



21.16 Noise generator – making use of electronic “trash“

Hi-fi freaks carry on a bitter fight against a phenomenon that physics has endowed us with; electrons live a life of their own and do not always do exactly what Ohm’s law says they should. They behave “statistically“, particularly at higher temperatures. The addition of energy in the form of heat causes them to move in ways which cannot be predicted. This causes what is known as “noise“ at the loudspeaker – a noise that is made up of an infinitely large number of frequencies. Every component produces noise, from the simple resistor to the transistor and great efforts have been necessary to develop particularly low noise transistors for amplifier input stages.

You are now going to produce deliberately as big a noise as possible and in doing this you will make use of the fact that a diode becomes conducting in the “wrong“ direction if the voltage is high enough. This does not do the diode any harm if you make sure that this “reverse“ current remains small by putting a resistor in series. This is known as the “breakthrough“ of the diode and a controlled breakthrough (current limited) possesses the, for us, enchanting property that the processes occurring are largely statistical in nature and thus accompanied by a loud noise. Circuit diagram 296 shows a noise generator, where the base-emitter diode of a normal transistor is employed to generate noise (you can see that the collector is not connected in). The emitter of the noise diode is not connected to the battery supply but to the “high voltage generator“ described in the last section, because the breakthrough of a

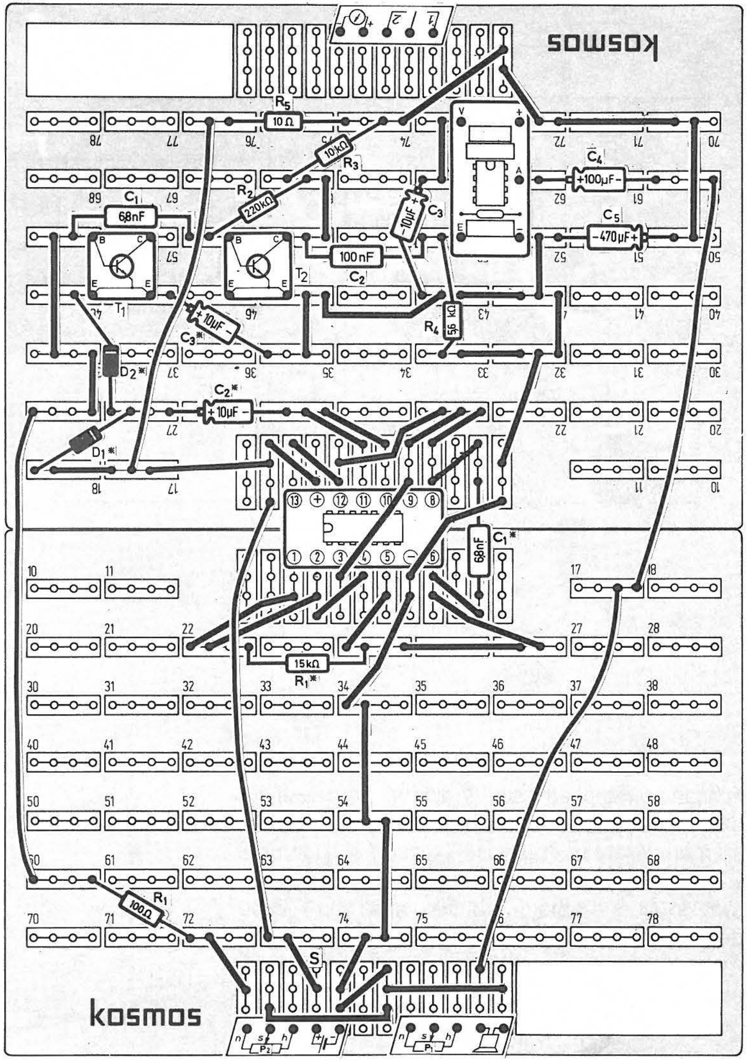


Fig. 295 Construction of circuit 296

base-emitter diode usually only occurs at voltages over 12V. The construction of the noise generator is shown in Fig. 295 – the voltage doubler left out of the circuit diagram is also illustrated here. After switching the voltage supply on turn P2 slowly, until a powerful noise can be heard. A high whistle possibly occurring at the same time need not bother you, this comes from the astable multivibrator, which shares its diligent activity

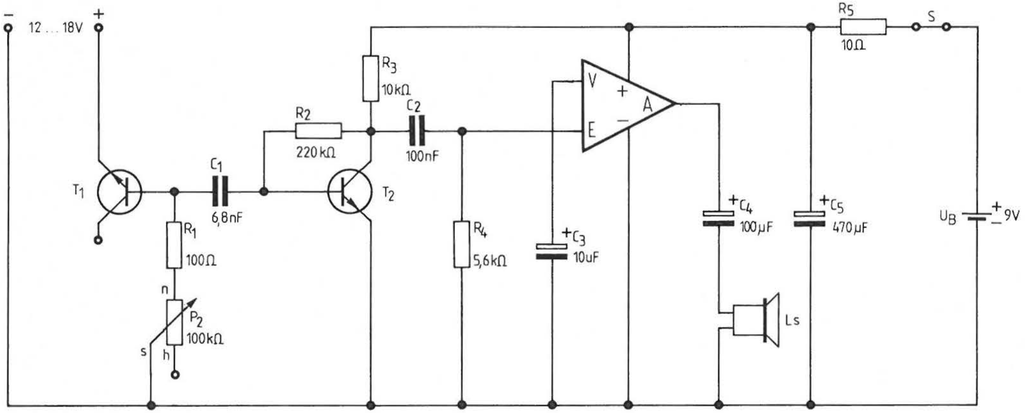

- 12 ... 18V +
T1
C1
6,8nF
R1
100Ω
n
P2
100kΩ
s
h
R2
220kΩ
R3
10kΩ
C2
100nF
T2
R4
5,6kΩ
+C3
10uF
V
+
A
E
–
+C4
100µF
Ls
R5
10Ω
S
+C5
470µF
UB
+ 9V

Fig. 296 Noise generator

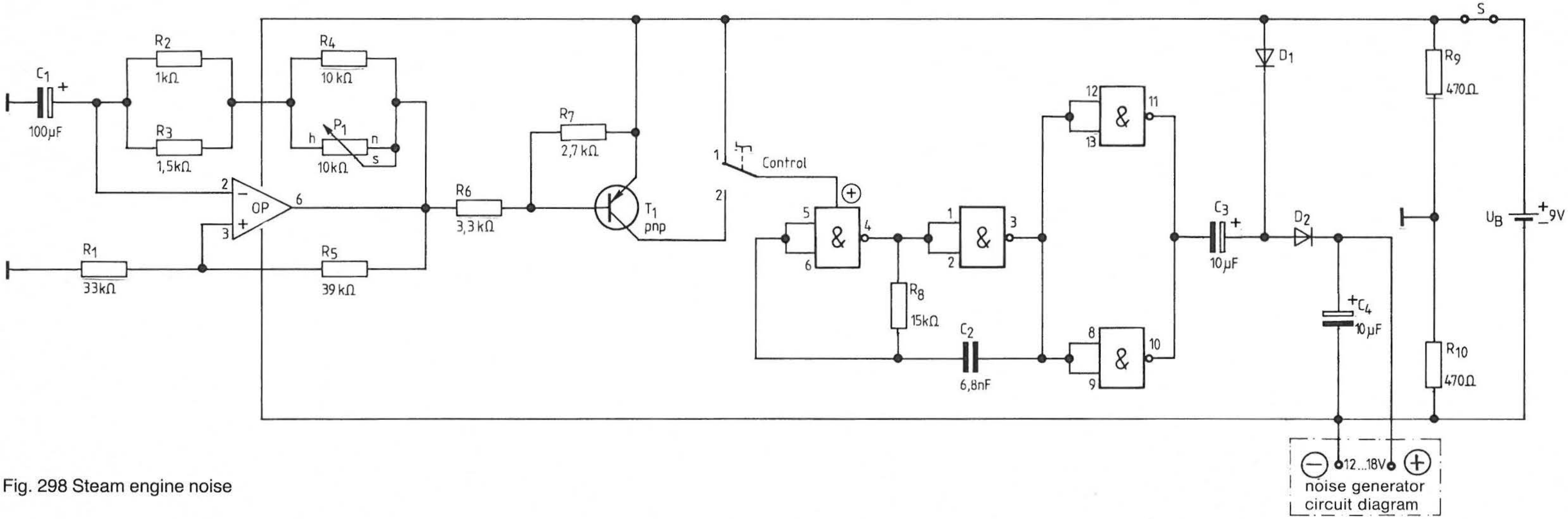

C1
+
100µF
R2
1kΩ
R3
1,5kΩ
R1
33kΩ
2
–
OP
+
3
6
R4
10 kΩ
P1
h
n
s
10kΩ
R5
39 kΩ
R6
3,3 kΩ
R7
2,7 kΩ
T1
pnp
1
2
Control
⊕
5
6
4
&
1
2
3
R8
15kΩ
C2
6,8nF
12
13
11
8
9
10
C3
+
10µF
D1
D2
+C4
10µF
S
R9
470Ω
R10
470Ω
UB
+ 9V
⊖ 12...18V ⊕
noise generator
circuit diagram

Fig. 298 Steam engine noise

with the rest of the circuit.
What use can noise be? We will go into this question in the next two sections.

21.17 Noisy transistor – puffing steam engine

Model railroaders want their layouts to be as realistic as possible and that includes sound too; the little engines should puff and pant just like their big prototypes. Electronics is very helpful here too and delivers noise to order – if you are willing to be genereous and accept the noise as being the puffing and panting of a steam engine.
Rebuild the noise generator according to Fig. 298; the postive supply voltage of the digital module is led to the collector of a p-n-p transistor, which is switched on and off by an astable multivibrator (made up from the OP AMP). The speed of the "train" can be continually changed by means of P1 (Fig. 297).
Suggestions for experiments: Take out the 470μF capacitor $C5$ and the note changes.

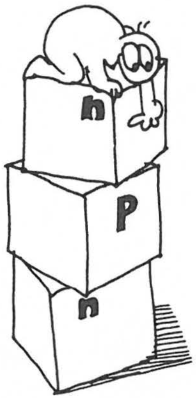
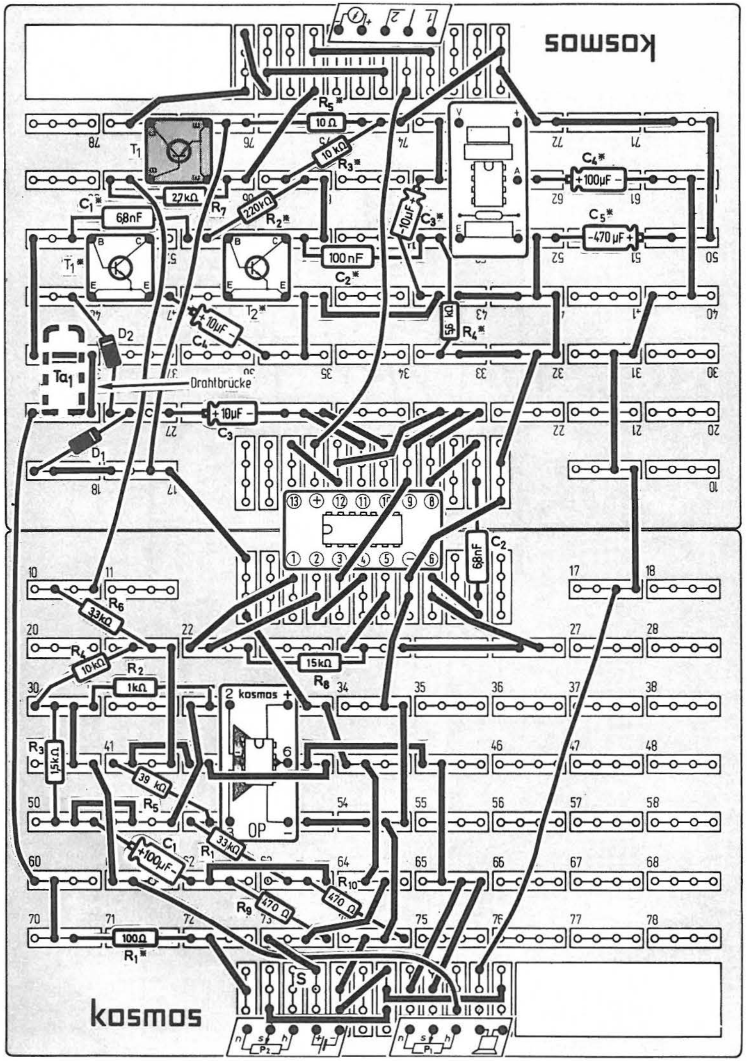


Fig. 297 Construction of circuit 298


kosmos
T1
R5*
10 Ω
10 kΩ
R3*
27 kΩ
R7
220 kΩ
R2*
C1*
68nF
100 nF
C2*
T1*
T2*
10µF
C3*
C4*
+100µF
C5*
470 µF
5,6 kΩ
R4*
D2
Ta1
Drahtbrücke
10µF
C3
D1
68nF
C2
R6
33kΩ
R4
10kΩ
R2
1kΩ
15kΩ
R8
2 kosmos
OP
R3
15kΩ
39 kΩ
R5
C1
+100µF
R1
33kΩ
R9
470 Ω
R10
470 Ω
100Ω
R1*
P2
P1
kosmos

Replace the 6.8nF capacitor *C1* by a 0.1 μF capacitor, a slight change in the note will be recognizable.

21.18 Noises in rhythm – electronic percussion

The noise generator can also be employed for another purpose; electronic percussion is produced when the wire connector Br is removed and the contact maker, shown with the broken line in Fig. 298, is employed. Rhythmic depression of the contact maker produces a noise that sounds very like a drum.
Suggestions for experiments:
The alterations suggested in the previous section can also be carried out here.

21.19 Gate delays - monoflop by logic

It would be wrong to maintain that gates can do everything if it were not possible to realize the classical electronic circuit with them, the monoflop. We will leave it to your imagination to decide what you switch on for a set period of time and then switch off again, it can be a simple LED or it can (via the KOSMOS mains switch X) be the lamp of an enlarger in a darkroom, or stairway lighting or an alarm siren. Look at the basic circuit

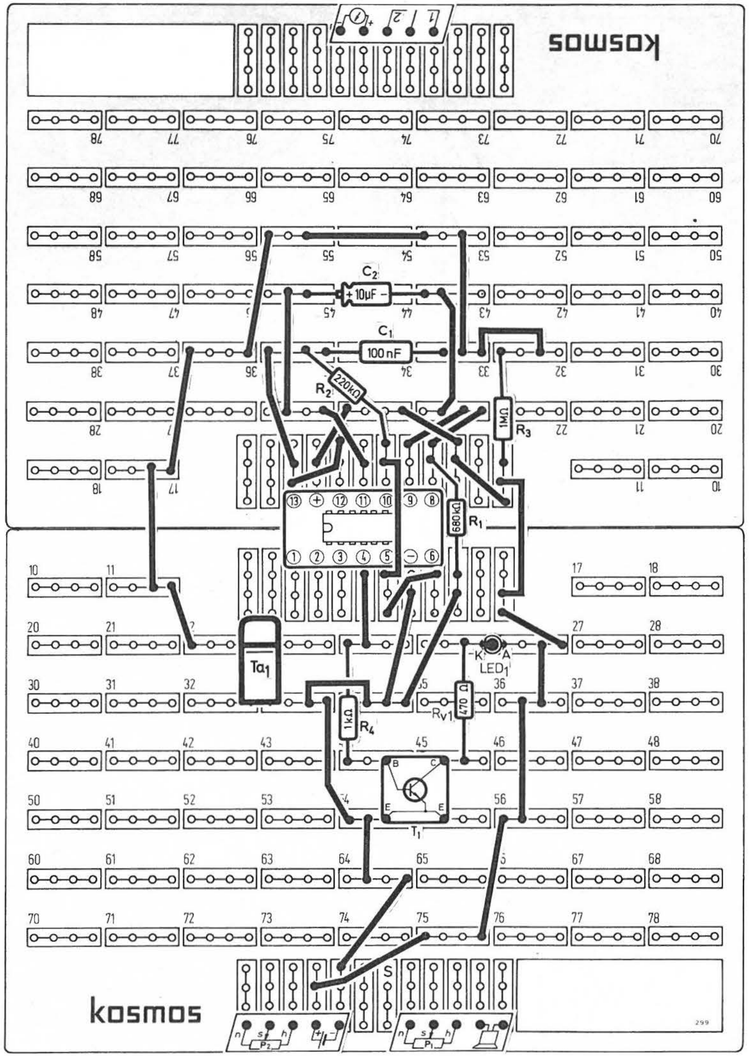


Fig. 299 Construction of circuit 300

– those of you who like experimenting will surely be able to think of a wide range of applications.

Figure 299 shows the construction, Fig. 300 the circuit diagram. In the resting state the output of inverter no. 2 is at high, the outputs of the buffer connected after (inverter no. 3) and that of inverter no. 1 are both at low. If the contact maker is now depressed, then the input of inverter no. 1 receives a negative impulse and its output goes to high for a short period and so sends a positive impulse to the input of inverter 2 whose ouput necessarily goes to the low state. The LED is illuminated via inverter 3. This state would remain held – if capacitor *C*2 did not recover from the effects of the positive impulse via resistor *R*1; the voltage at its right-hand connection drops continuously, until it reaches a value, that is perceived as a low by the input to inverter 2. Its output then returns to high, that of inverter 1 to low and the orginal state is re-established, the LED goes out.

Suggestions for experiments:

Various combinations of values can be tried out for *R*1 and *C*2. Times of several minutes can be achieved – the values given here yield a switching on time of just about 6 seconds.

21.20 Punctual as the clock - recording the passing of time

Now for the last example (for the moment) of the application of NAND gates we suggest a layout, which regularly emits a peep – rather like that on the radio before the hour is announced: peep – peep – peep... For this you employ two astable multivibrators, one produces the peep, the other oscillates much less rapidly and decides the interval between and the duration of the peeps. There is also a contact maker in circuit diagram 302; this has to be depressed, to set the time marker in action.

Suggestions for experiments:

The amplifier module can naturally be employed to drive the loudspeaker, instead of using a p-n-p transistor with the earphone.

Fig. 300 Monoflop with gates

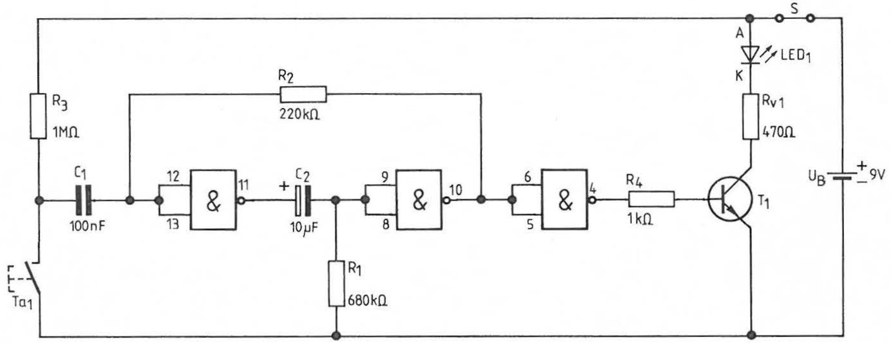
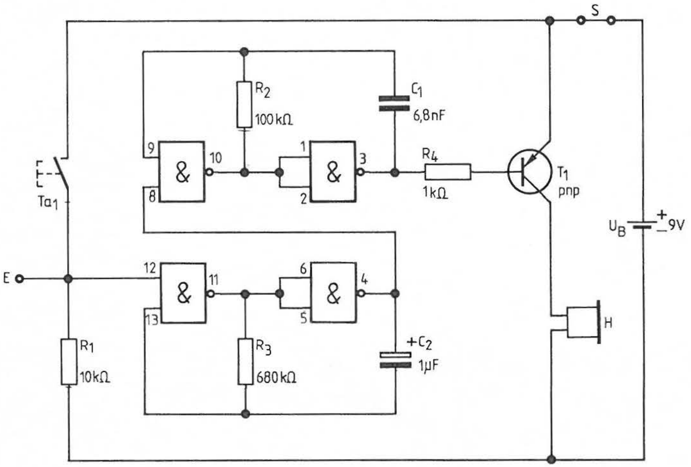


Fig. 302 Alarm generator



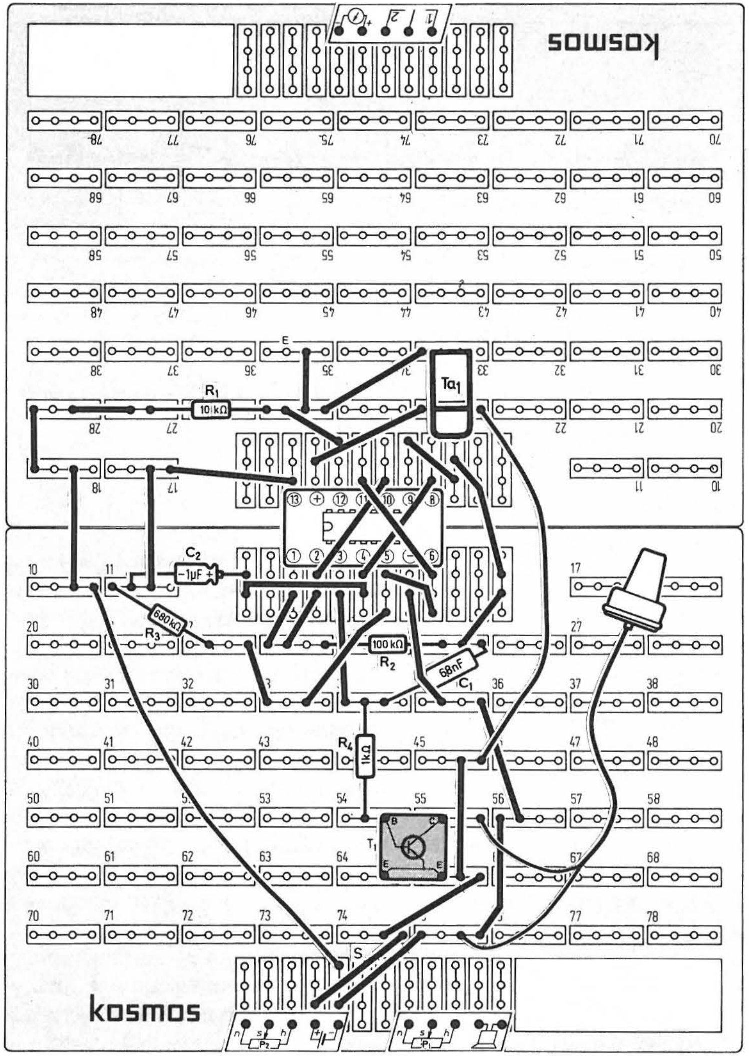


Fig. 301 Construction of circuit 302

21.21 Cannot be missed - audible alarm generator

The input E in circuit diagram 302 has not yet been discussed; let us do that now. The interrupted peep note can be employed for any alarm circuit you like – for example it can be combined with the cold monitor in Section 11.16. The right-hand side of the cold monitor circuit is omitted and the collector of the right-hand transistor connected to input E of our alarm signal generator. If the temperature rises then a particularly penetrating alarm signal is emitted.
Suggestions for experiments:
Every circuit that can produce a "high" at its output, when a particular event takes place, can be connected to the input of the audio alarm generator.

21.22 NAND becomes OR

We want to continue to be "logical" and learn about another type of gate. To do this think about the inside light of an automobile and think what happens if we first open one of the front doors, and then the other and finally open both. The internal lighting will go on when one **or** the other **or** both the automobile doors are opened. One

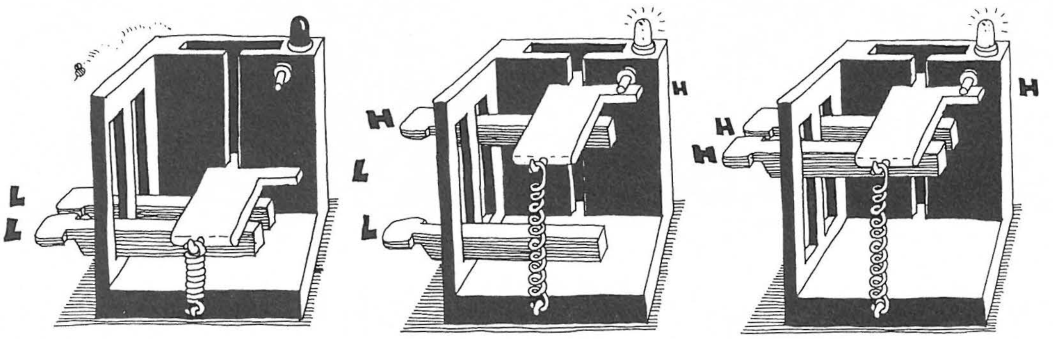


Fig. 303 Logic box for an OR gate

E_1	E_2	A
L	L	L
H	L	H
L	H	H
H	H	H

Fig. 304 Truth table for OR gate

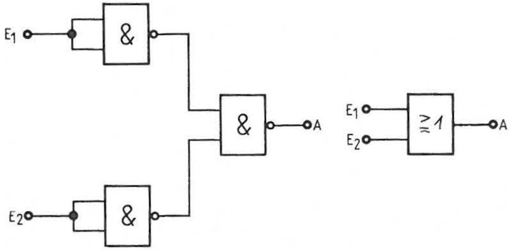


Fig. 305 Circuit diagram symbol for OR gate

condition or the other or both must be fulfilled in order to get a result (the inside light going on). Such a set of conditions is known as an **OR** gate.
The logic box in Fig. 303 is intended to help your understanding once again. If both input slides are at low then the internal slide that activates the output lamp is also low. If one of the two input slides is raised, then it carries the output slide with it and this lights up the lamp. This is naturally also true when both input slides are at high. The logic is that high at one input is sufficient to put the output to high too. This relationship has been entered in the truth table in Fig. 304.
Figure 305 shows the circuit diagram symbol for an OR gate and it also shows how an OR gate can be constructed from three NAND gates.

Let us leave theory and look at practice with a test circuit according to Fig. 306. Depressing one or the other or both or none of the contact makers will allow you to test out the "truth content" of the table in Fig. 304. The appropriate circuit diagram is illustrated in Fig. 307.

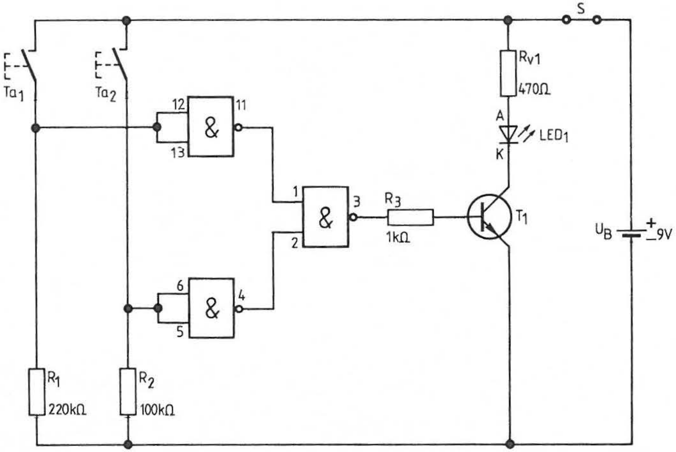


Fig. 307 Test circuit for OR gate

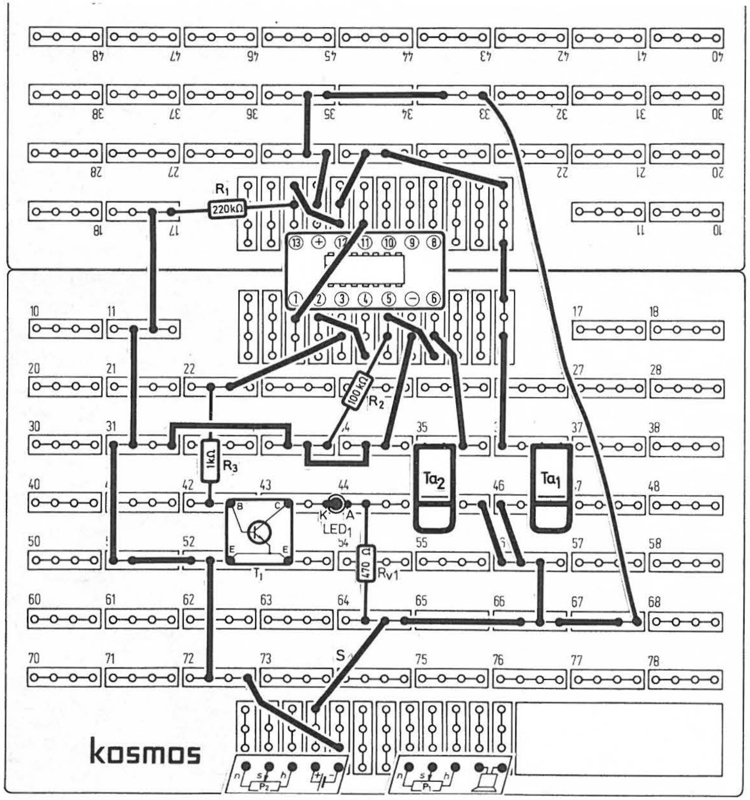

R1
220kΩ
R2
100kΩ
R3
1kΩ
T1
LED1
Rv1
470 Ω
Ta2
Ta1
S
kosmos

Fig. 306 Construction of circuit 307

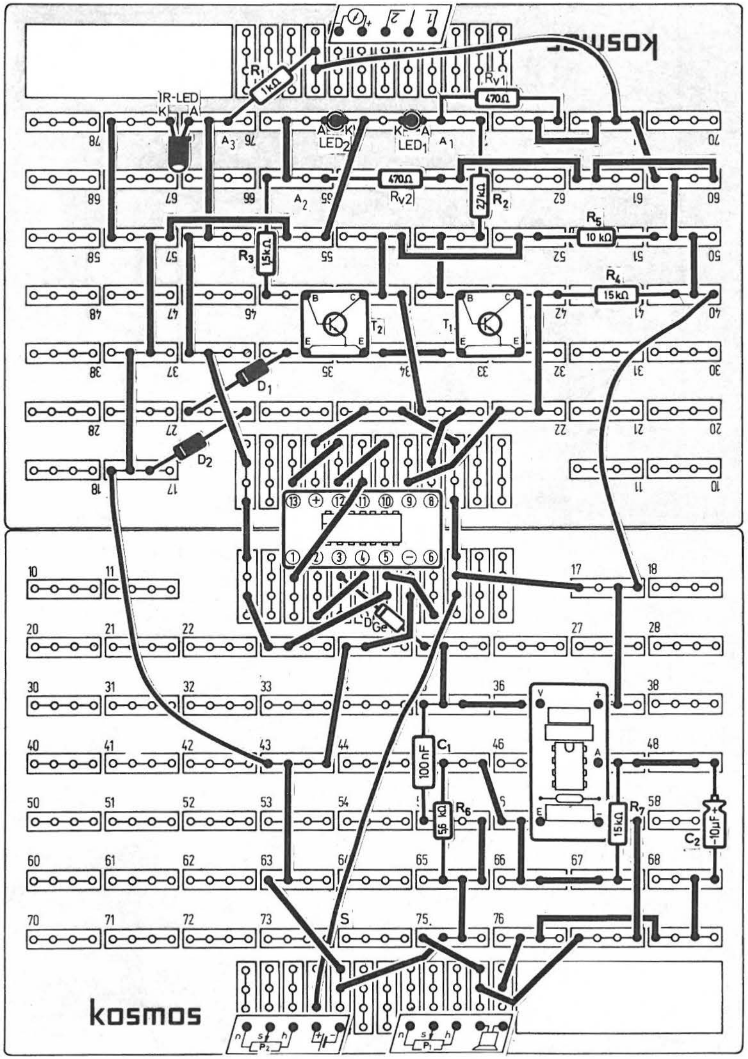

kosmos
R1
1kΩ
IR-LED
K A
A3
LED2
LED1
A1
A2
Rv1
470Ω
Rv2
470Ω
R2
27kΩ
R3
15kΩ
R5
10 kΩ
R4
15kΩ
T2
T1
D1
D2
DGe
C1
100 nF
R6
56 kΩ
R7
15kΩ
C2
10µF
S
kosmos

Fig. 308 Construction of circuit 309

21.23 At the space station - we are counting down...

...unfortunately it is always having to be interrupted, because the electronic monitoring system records an error. You can easily understand that given the possibility of hundreds of thousands or millions of defects every error does not report itself individually, rather the functional units are collected into groups, so that an alarm can mean, for example: error in unit 1 **or** in unit 2 **or** in unit 3.

We are going to build a supervision circuit to check on three components – 2 LEDs and an IR diode – and to give an alarm signal, when a current circuit is interrupted by removing one of the diodes. This is done by employing an OR gate with **three** inputs. Two of the necessary inversions are performed by transistors.

It is our aim to ensure that one of the inputs of the OR gate goes to high if an error occurs. Circuit diagram 309 illustrates how this can be accomplished. If one of the three diodes is removed, then the appropriate output A1 or A2 or A3 of the

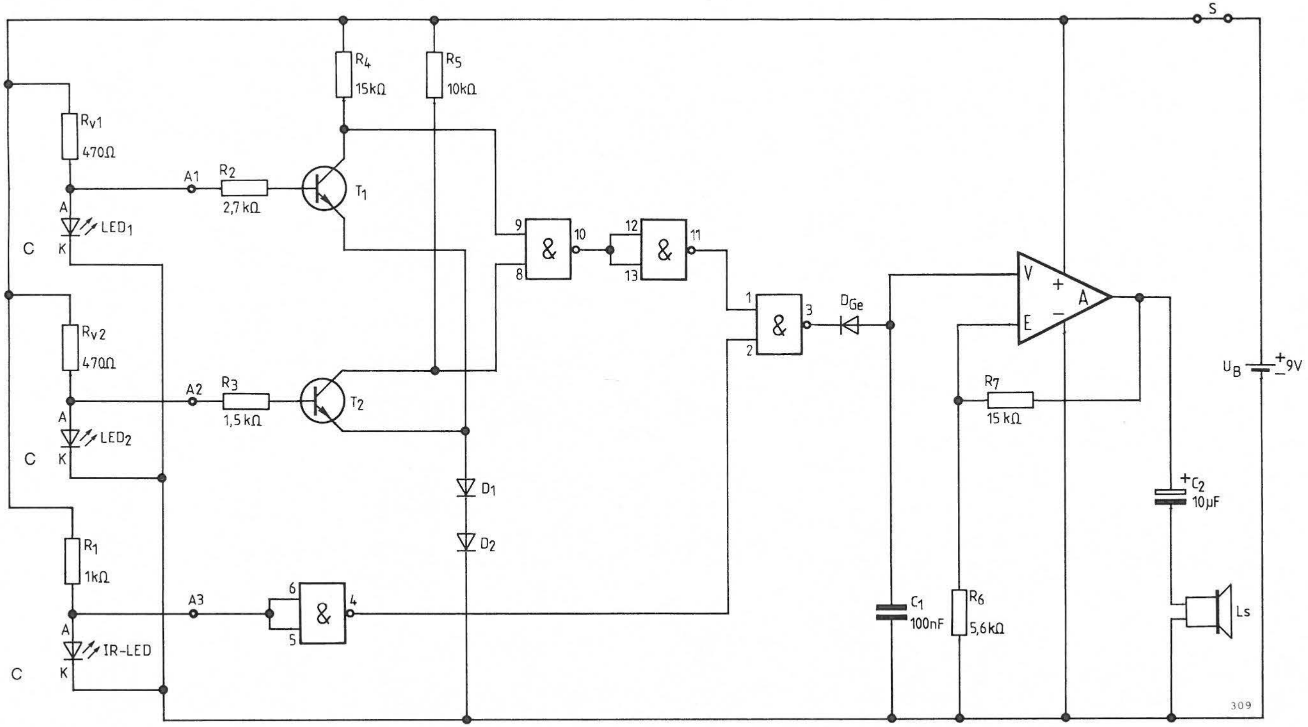

S
R4
15kΩ
R5
10kΩ
Rv1
470Ω
A1
R2
2,7kΩ
T1
A
LED1
C
K
9
8
&
10
12
13
&
11
1
2
&
3
DGe
V
+
E
−
A
UB
+9V
Rv2
470Ω
A2
R3
1,5kΩ
T2
A
LED2
C
K
R7
15kΩ
D1
D2
+C2
10µF
R1
1kΩ
A3
6
5
&
4
C1
100nF
R6
5,6kΩ
Ls
A
IR-LED
C
K
309

Fig. 309 Automatic component tester

diode conduction voltage (which is perceived as low by the gates or transistors) springs to the positive battery voltage, that is logically to high. The construction is shown in Fig. 308.
Let us not keep quiet about one problem: the circuit does not recognize an error if a diode "burns out", that is there is continuous conduction because of current overload. However, it would be possible to monitor this too by using further, more complicated electronics involving comparators.

E_1	E_2	A
L	L	H
H	L	L
L	H	L
H	H	L

Fig. 312 Truth table for a NOR gate

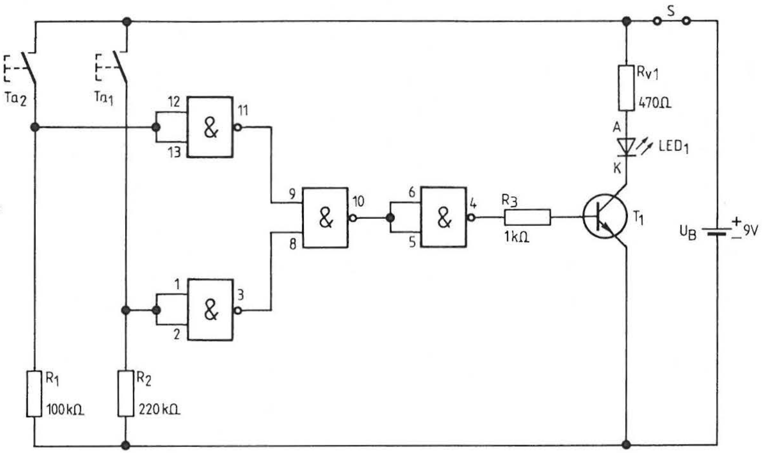


Fig. 314 Test circuit for a NOR gate

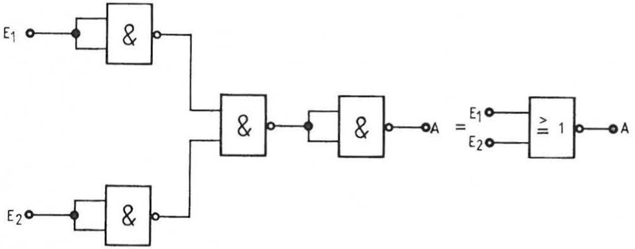


Fig. 310 Circuit diagram symbol of a NOR gate

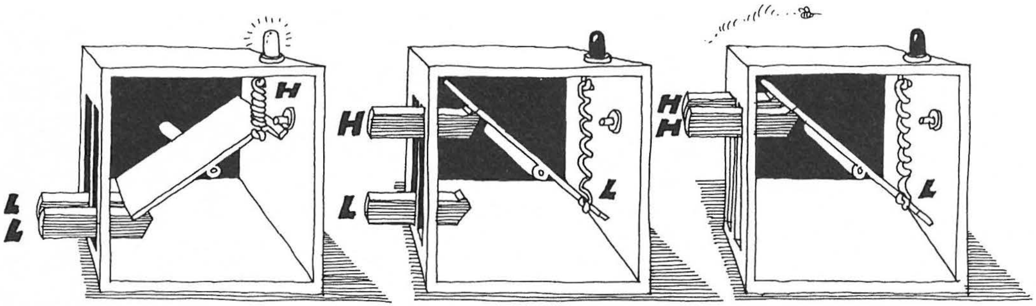


Fig. 311 Logic box for a NOR gate

21.24 OR negated gives NOR

It sounds absolutely logical from what you already know and it also gives an indication as to what must be done in order to turn the logic of an OR gate round; an inverter must be attached after it, that negates the output of the OR gate. As a test build the NOR circuit according to Fig. 313 (circuit diagram 314). If neither of the contact makers is depressed then the LED lights up; depressing one or both of the contact makers makes the LED go out.
This relationship is shown in Fig. 310, which also gives the circuit diagram symbol for a NOR gate. Figure 311 gives the appropriate logic box and Fig. 312 its accompanying truth table.

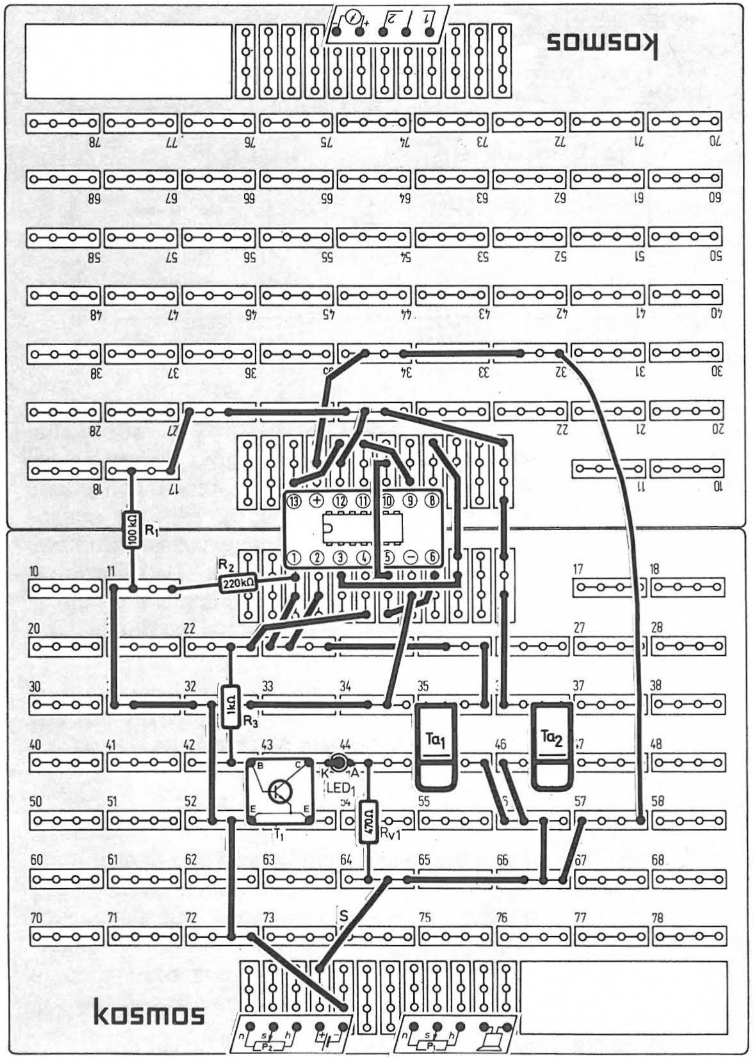


Fig. 313 Construction of circuit 314

21.25 High society - the exclusive-OR gate

This gate is worthy of consideration not just because of its snobbish name but also because of its astonishing properties. The exclusive-OR gate always reacts at its output when its inputs are at **the same logical values**. Thus a combination of high and low means output at high, high-high and low-low, on the other hand, make the output go to low. Thus this is a sort of "digital comparator" and in the next section you are going to build a device employing an exclusive-OR gate, which is called a "window comparator" on account of its properties (incidentally you have already made the acquaintance of exclusive-OR gate logic in the exercise in Fig. 283).

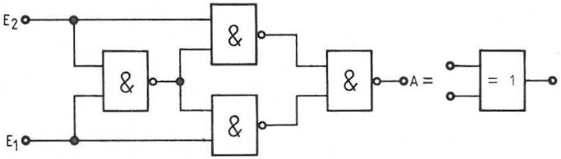


Fig. 315 Circuit diagram symbol for an exclusive-OR gate

E_1	E_2	A
L	L	L
L	H	H
H	L	H
H	H	L

Fig. 316 Truth table for an exclusive-OR gate

We will not bother with a logic box, since the model is more complicated than the reality and instead we will ask "what happens if..." questions concerning the exclusive-OR circuit diagram 315. You will have no difficulty in checking the truth table in Fig. 316 on the basis of the circuit diagram.

21.26 An electronic window for the light

Circuits that flip a comparator by increasing the voltage but which flip it back when the voltage increases even more, are known as **window comparators**. A "window" is cut, as it were, in the voltage increase, so that – otherwise than in a normal comparator – a result (e.g. a LED lighting up) is produced by its output over a particular **voltage range.**

Fig. 318 Window comparator

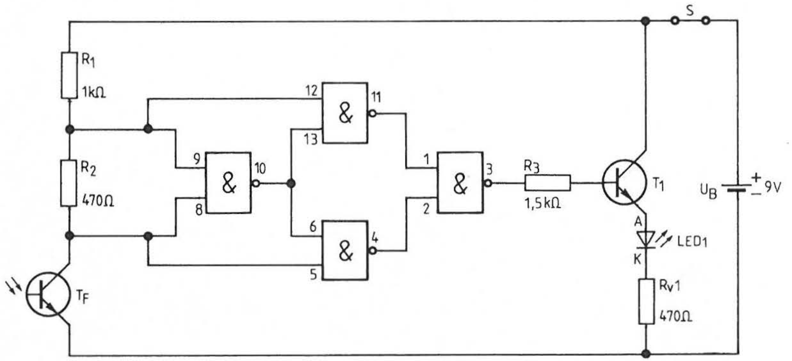
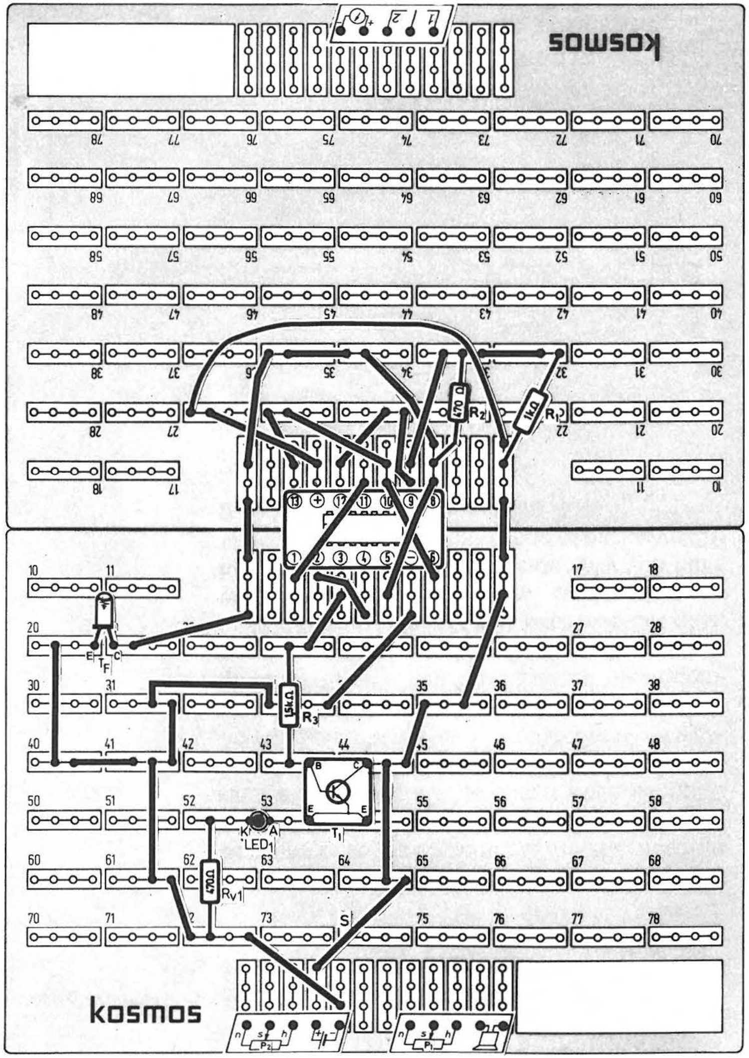

S
R1
1kΩ
12
11
&
13
9
10
&
1
3
&
R3
1,5kΩ
T1
U_B
+
–
9V
R2
470Ω
8
2
6
4
&
5
A
LED1
K
Rv1
470Ω
T_F

Fig. 317 Construction of circuit 318


kosmos
470Ω
R_2
1kΩ
R_1
E
T_F
C
1,5kΩ
R_3
B
C
E
E
T_1
K
A
LED1
470Ω
R_{V1}
S
P_2
P_1
kosmos

The window comparator that we are envisaging reacts towards different intensities of light (construction 317, circuit diagram 318). If a lamp is brought slowly towards the phototransistor Tf the LED goes on, if the lamp is brought even closer to Tf then the LED goes out again; the process is reversed if the lamp is slowly removed from Tf. Figure 319 illustrates this process by means of a diagram.

The practical use? Well a particular brightness can be continually monitored, if the brightness gets too low or too high the control lamp goes out. This circuit can also be employed for other parameters, such as temperature, humidity, sound, voltage, current and so on.

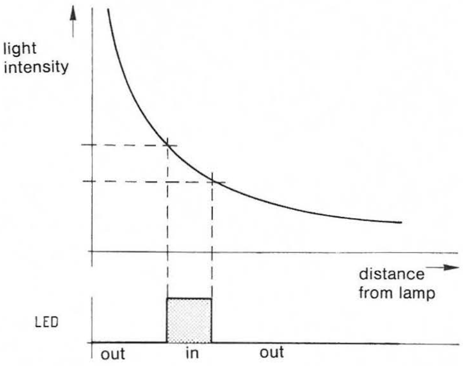


Fig. 319 Diagram explaining window comparator

21.27 Agent-proof reflection light barrier

The advantage of an exclusive-OR gate can be exploited in this next circuit. First of all a few words of explanation concerning the term "reflection light barrier". It is an arrangement whereby the light beam is never received directly but is reflected from some object or other and is thus "redirected" onto a receiver transistor, so that it is not necessary to separate the transmitter and receiver from each other in space (Fig. 320).

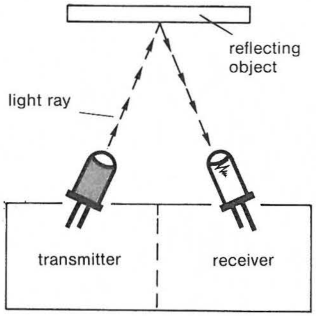


Fig. 320 Diagram of a reflection light barrier

Our light barrier is said to be "agent-proof" because it reacts very distinctly to "illegal disturbances"; if you try to "hoodwink" it with another light (e.g. by shining a flashlight on it) then it gives an audible warning sound. It only operates properly when it receives the light beam that it transmits itself. Foreign lights and changing local brightness are always reacted to in the above manner. In order for the reflection light barrier to function properly it is necessary to carry out the experiment in a darkened room!

It is the exclusive-OR gate in circuit 322 which is responsible for the safety á la James Bond. If the logical signals from transmitter and receiver are the **same** at its inputs then the output goes to low, if they are **not the same** (input light does not correspond to output light) then there is a square wave potential at the output. The comparator OP AMP evaluates this with the aid of the integrating capacitor C3 and controls the LED.

Putting the layout according to Fig. 321 into operation:

Arrange the phototransistor and the IR diode as shown diagrammatically in Fig. 320. Place a piece of white paper a few centimeters in front of the phototransistor and IR diode and turn P1 until the LED is continuously lit. In this situation point a flashlight at the phototransistor, now adjust the potentiometer so that a warning note is produced. The adjustment is now complete and you will be able to demonstrate the following effects. Because of the integrating effect of the capacitor C3 the LED is delayed in going on and off; if you remove the piece of white paper and shade the phototransistor with your hand (or darken the room) then the LED goes out; allow light to fall on the phototransitor and the alarm sounds; place a piece of paper in front of the transmitter and receiver, the LED remains on continuously; illuminate

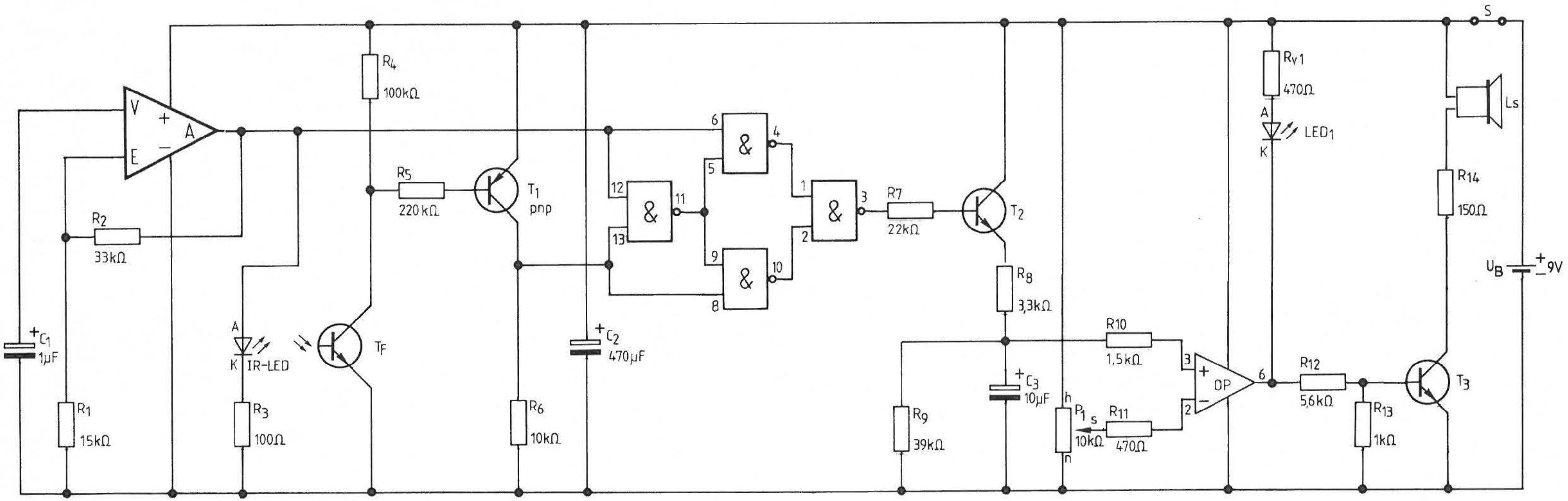

S
V
E
A
R4
100kΩ
R5
220kΩ
T1
pnp
R2
33kΩ
6
4
5
12
11
13
9
10
8
1
3
2
R7
22kΩ
T2
R8
3,3kΩ
Rv1
470Ω
A
LED1
K
Ls
R14
150Ω
UB
9V
+C1
1µF
R1
15kΩ
A
K
IR-LED
R3
100Ω
TF
+C2
470µF
R6
10kΩ
R9
39kΩ
+C3
10µF
h
P1
s
10kΩ
n
R10
1,5kΩ
R11
470Ω
OP
R12
5,6kΩ
R13
1kΩ
T3

Fig. 322 “Agent-proof“ light barrier

Solutions to exercises 1 and 2 in Section 21.10

the phototransistor additionally with a foreign light and the alarm sounds again.
It is possible to detect when the light received corresponds to that transmitted!

E_1	E_2	A
L	L	L
L	H	H
H	L	H
H	H	H

E_1	E_2	A
L	L	L
L	H	H
H	L	H
H	H	L

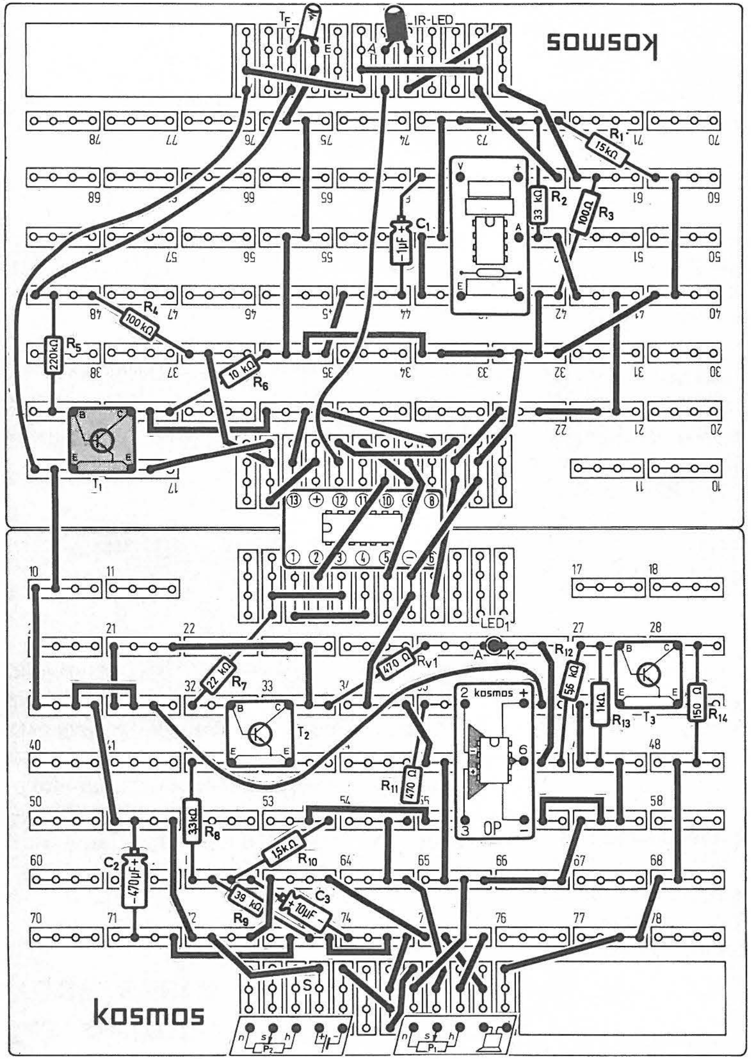

kosmos
T_F
C
E
A
K
IR-LED
R1
15kΩ
R2
33 kΩ
R3
100Ω
C1
1µF
R4
100 kΩ
R5
220kΩ
R6
10 kΩ
T1
B
C
E
13
+
12
11
10
9
8
1
2
3
4
5
−
6
LED1
R7
22 kΩ
T2
RV1
470 Ω
R12
5,6 kΩ
R13
1kΩ
T3
R14
150 Ω
2 kosmos +
OP
3
R11
470 Ω
R8
33kΩ
R10
1,5kΩ
C2
470µF
R9
39 kΩ
C3
10µF
S
P2
P1
kosmos

Fig. 321 Construction of circuit 322

E1	E2	E3	E4	A
L	L	L	L	L
L	L	L	H	L
L	L	H	L	L
L	L	H	H	H
L	H	L	L	L
L	H	L	H	L
L	H	H	L	L
L	H	H	H	H
H	L	L	L	L
H	L	L	H	L
H	L	H	L	L
H	L	H	H	H
H	H	L	L	H
H	H	L	H	H
H	H	H	L	H
H	H	H	H	H

E1	E2	E3	E4	A
L	L	L	L	H
L	L	L	H	H
L	L	H	L	H
L	L	H	H	L
L	H	L	L	H
L	H	L	H	H
L	H	H	L	H
L	H	H	H	L
H	L	L	L	H
H	L	L	H	H
H	L	H	L	H
H	L	H	H	L
H	H	L	L	H
H	H	L	H	H
H	H	H	L	H
H	H	H	H	H

Solutions to exercises 3 and 4 in Section 21.10

22. Semiconductors with four layers

Transistors with n-p-n layers ("n-p-n transistors") are now very familier to you, you have also employed the complementary p-n-p type in some experiments and found out that they are connected with all the polarities reversed (emitter at positive, collector at negative, transistor made to conduct by connecting the base to negative via a protective resistor).

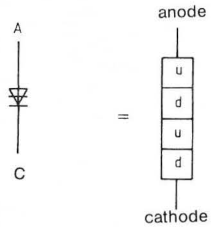


Fig. 323 Diagram and circuit diagram symbol of a four-layer diode

There are also semiconductor components with four layers in the order p- n-p-n. They are equipped with two outputs (the anode connection at the outer p layer and the cathode connection at the outer n layer); they are known as **four-layer diodes** (Fig. 323). If these diodes are driven in the conducting direction (anode to positive) then they are nonconducting at first, but then if the voltage between cathode and anode is continually increased the diode suddenly becomes conducting, it "triggers" – the corresponding anode-cathode voltage is called the triggering voltage.

22.1 Ignition on - the thyristor

If you imagine a third connection at the p layer next to the cathode then the four-layer diode has become a **thyristor**. This third connection is known as a **gate**, it is possible to use it to trigger the four-layer arrangement at any voltage below the triggering voltage. However, after it has been triggered, it is not possible to "switch off" the thyristor without further ado, because the gate is completely ineffective once the anode current is flowing, so that a short "triggering impulse" at the gate is sufficient to bring the conduction process into action. The anode current discontinues when external influences make it so low that it falls below what is known as the "holding current". The thyristor then ceases to conduct and is ready to be triggered again by another impulse at the gate. The circuit diagram symbol for a thyristor is shown in Fig 324.

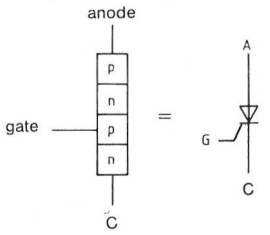


Fig. 324 Diagram and circuit diagram symbol of a thyristor

The thyristor idea is particularly beloved of automobile manufacturers who employ it in thyristor-controlled ignition circuits which are becoming more and more common.

22.2 Two complementary transistors make up a thyristor

You can make up the four-layer arrangement without any problems using a n-p-n and a p-n-p transistor and produce a perfect reproduction of a thyristor. Figure 325 shows the principle of such a circuit. Figure 326 shows the practical realization of a thyristor (circuit diagram 327). If the battery supply is connected then the thyristor remains nonconducting, the LED does not light up. Only when the gate contact maker is depressed for a short while does triggering take place, the thyristor now remains conducting and can only be made nonconducting by switching the supply voltage off. The resistor *R*1 ensures that the arrangement is not triggered by a stray impulse.

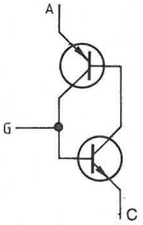


Fig. 325 Formation of a thyristor from a p-n-p and a n-p-n transistor

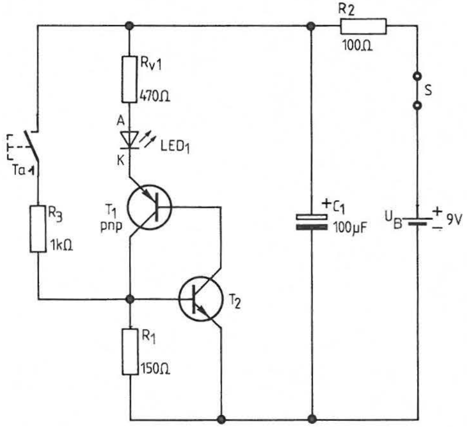


Fig. 327 Triggering circuit for a thyristor

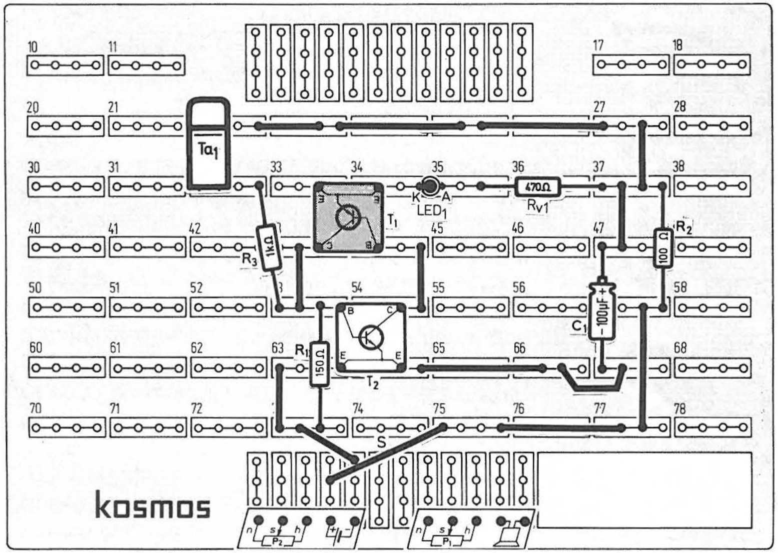


Fig. 326 Construction of circuit 327

Suggestions for experiments:
Remove capacitor *C*1 and switch the battery on and off several times. If can happen that the thyristor will trigger of its own accord without a positive impulse at the gate; this is because a sudden increase in the anode voltage can have a triggering effect. The capacitor in your circuit provides for a “controlled“ increase in voltage.

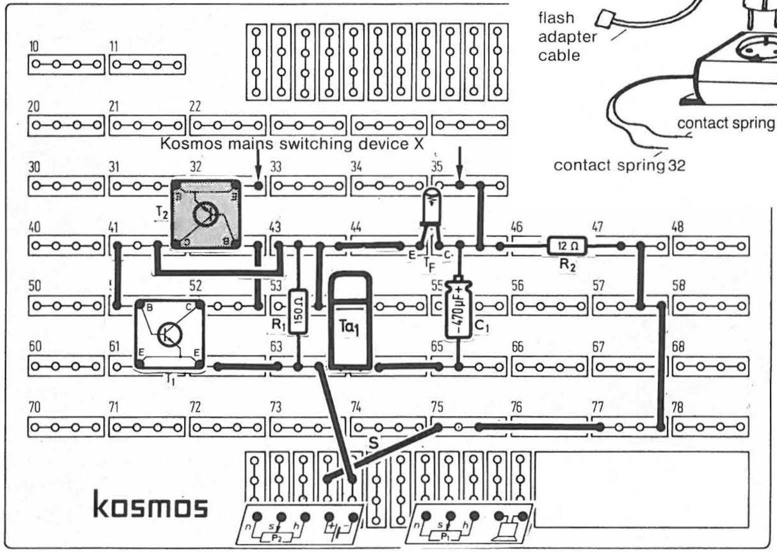
22.3 A thyristor-controlled second flash trigger

Photographers like to be able to set off a second flash automatically to light their subjects additionally without having to have cables “getting under their feet“. The light from the main flash (which is connected to the camera) falls on the phototransistor of the second flash circuit; the transistor becomes conducting for a fraction of a millisecond, it transmits a positive impulse to the gate and the thyristor is triggered. The second flash is then set off via relay i.e. the KOSMOS mains switch X. In order to prepare for the next flash the contact maker is depressed thereby making the thyristor nonconducting again.
Figure 329 shows the circuit diagram of the second flash trigger. When constructing it according to Fig. 328 a certain amount of cunning is required to get the connection between the elec-

tronics and the flash apparatus, but it should be possible, according to the sketch, without too many problems.

Note: Professional second flash triggers do not have to be reset by means of a contact maker, because in these the flash contact is parallel to the thyristor; when the flash goes off the anode current goes practically down to zero and the thyristor becomes nonconducting of its own accord. However to do this it has to be suitable for an off state voltage of 150 – 300V, and since our thyristor will only hold back about 40V we have had to use the dodge of the relay and the reset contact maker.

Fig. 328 Construction of circuit 329


Kosmos mains switching device X
T2
T1
R1
150Ω
Ta1
470µF
C1
12 Ω
R2
TF
E
C
B
S
P2
P1
kosmos

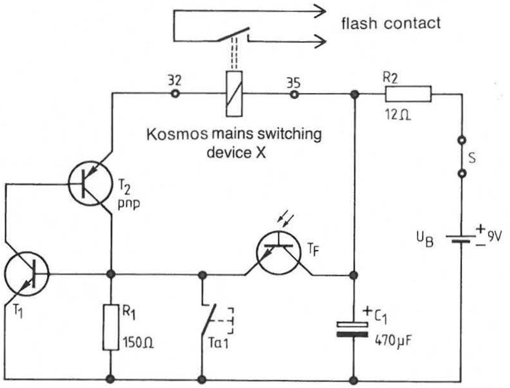
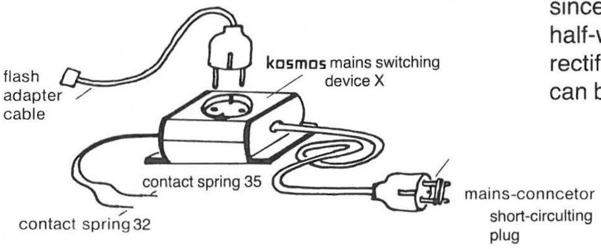

flash contact
32
35
R2
12Ω
Kosmos mains switching device X
S
T2
pnp
TF
UB
+9V
T1
R1
150Ω
Ta1
+C1
470µF

Fig. 329 Second flash trigger with thyristor


flash adapter cable
kosmos mains switching device X
contact spring 35
contact spring 32
mains-conncetor short-circulting plug

22.4 SCR = silicon controlled rectifier

Thyristors are members of the group of controlled rectifiers known as **s**ilicon **c**ontrolled **r**ectifiers (SCR). They are called rectifiers because, like diodes, they only allow a current to pass in one direction, they are said to be controlled because a gate is used to control the time point at which they are to be conducting.
Imagine an alternating current with a sine shape, it naturally has positive and negative half-waves (Fig. 331) applied to a diode (Fig.330). The negative half-waves would be cut out after the diode, since the diode is only conducting for the positive half-waves (Fig. 332). A thyristor also has such a rectifying effect, when it is continously triggered it can be employed instead of the diode.

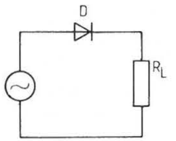


Fig. 330 Alternating current circuit with diode and load resistance

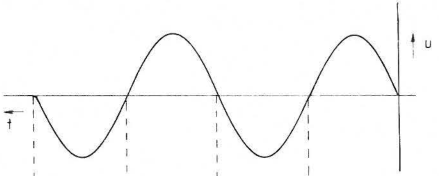


Fig. 331 Voltage-time curve for alternating current

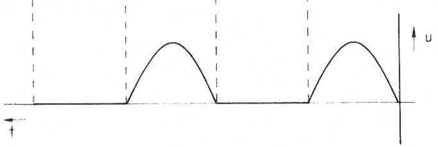


Fig. 332 Voltage-time curve after rectification with a diode

Now let us use the gate to decide when we want the thyristor to be triggered; for instance we wish the thyristor only to become conducting when the positive half-wave has reached its maximum (peak value). Figure 333 shows our requirement in a voltage time diagram; the voltage at the non-conducting thyristor increases, when the peak value is reached the thyristor begins to conduct. Since the thyristor is now conducting its anode-cathode voltage drop falls to the (extremely small) conducting level. When the externally applied sine wave nears its zero value it falls below that required to provide the holding current for the thyristor, this then returns to the nonconducting state of itself and the whole process begins again with the next positive half-wave.

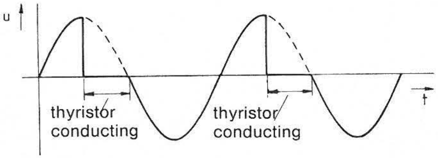
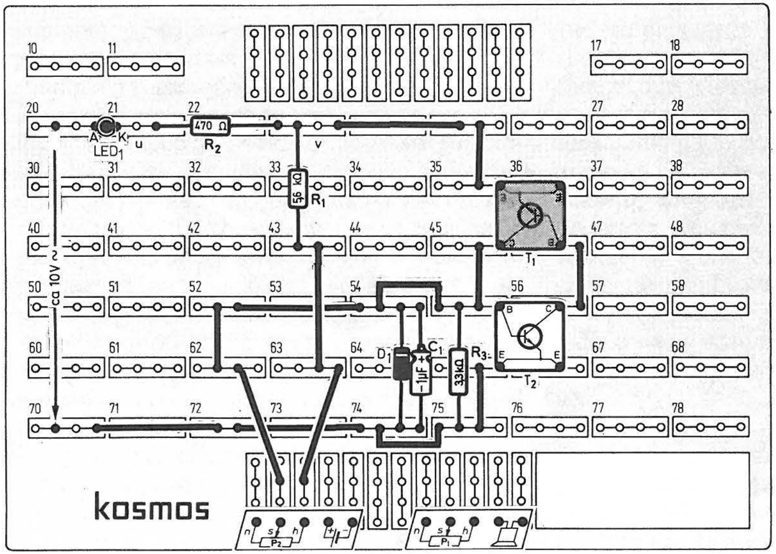
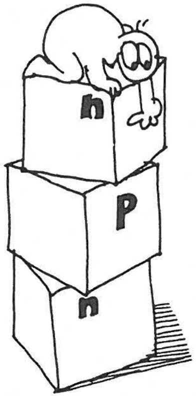


Fig. 333 Voltage-time curve with a thyristor

Fig. 334 Construction of circuit 335


10
11
17
18
20
21
22
27
28
A
K
LED1
u
470 Ω
R2
v
30
31
32
33
34
35
36
37
38
56 kΩ
R1
40
41
42
43
44
45
47
48
T1
ca 10V ~
50
51
52
53
54
56
57
58
B
C
E
60
61
62
63
64
D1
C1
1µF
33kΩ
R3
T2
67
68
70
71
72
73
74
75
76
77
78
kosmos
P2
P1

How can this behavior be controlled at the gate? That will be investigated on the basis of an example, in the next section.



22.5 Dimmer with phase-shift control

The technique of making a thyristor conducting at a chosen time point on the sine wave is known as **phase-shift control**. Figure 335 illustrates the circuit. The capacitor is charged via resistor *R*1 and potentiometer P2, as the positive half-wave rises, until a voltage is reached that is sufficient for the gate to trigger the thyristor; this then becomes conducting and the capacitor can discharge via the gate. P2 changes the time constant of the charging process, so that adjusting the potentiometer makes it possible to set exactly at what time – after the commencement of the positive half-wave – the thyristor is triggered.

If triggering occurs immediately after the half-wave commences then a powerful current flows on average, because the thyristor is conducting for the whole of the half-wave period. On the other hand, if triggering only occurs shortly before the half-wave is complete then the time, during which the thyristor is conducting, is short and the average current is then correspondingly low.

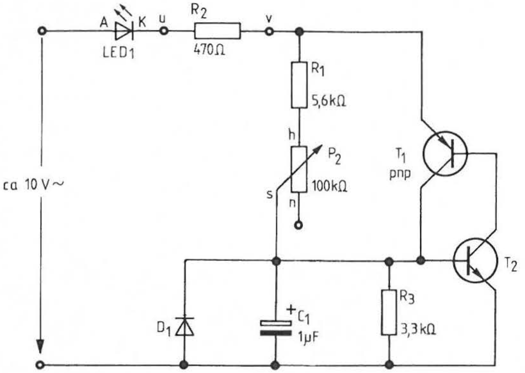
Figure 336 shows a **current**-time diagram for the connecting leads of resistor *R*2, that has been recorded with an oscilloscope. You can see quite clearly that as the current reaches its peak value it suddenly begins to flow through the resistor (and hence through the LED). Of course no current flows during the negative half-wave. The broken line represents the original sine curve.

Diagram 337 reproduces a **potential** oscillogram taken at the contacts of the thyristor (anode and cathode). It can be seen here that the voltage of the positive half-wave increases at first, since the thyristor is (still) nonconducting. There is then a steep drop, a sign that the thyristor has been triggered. The negative half-wave does not appear here because the LED also has a rectifying action.

In order to build the construction in Fig. 334 you require a sine alternating current with a voltage of about 10V, which can best be obtained from a model railroad power supply (that must have an ac output!), a normal bell transformer or from the KOSMOS computer power supply. **On no account must you experiment with 110V out of the socket!** The sine wave ac is connected as shown and P2 is slowly turned from left to right. The LED begins to glow and gets brighter and brighter until it reaches its full brightness.

The particular speciality of this simple dimmer is that the brightness is adjusted **without current**

Fig. 335 Phase-shift control



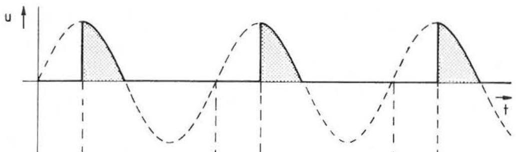


Fig. 336 Current-time curve at the load resistance

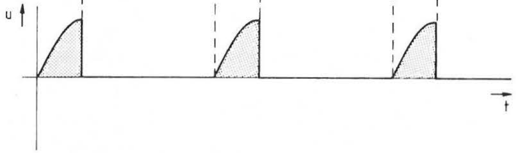


Fig. 337 Voltage-time curve at the thyristor in circuit 335

being transformed into heat. In all the circuits you have met up to now heat was produced when the LED was dimmed (however, only in small amounts at the low currents we work at). With high and very high currents – e.g. controlling the rate of rotation of railroad locomotive motors – phase-shift control is of enormous advantage; it is not necessary to turn current into useless heat energy and the cooling problems are considerably reduced. This branch of electronics incidentally is known as **power electronics**.
Dimmers for household lighting that work on the phase-shift control principle are commercially available; so that your circuit is a true-to-life model of an actual practical application.

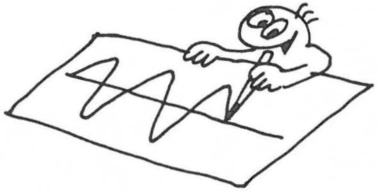
23. Amplifier class system

Amplifier quality is measured by how undistorted (pure) the sine waves are that are reproduced at the output. If the beautiful sine wave is bedraggled then it sounds dreadful to the trained ear; the amplifier involved is then said to have a high **distortion factor**. This is calculated according to a rather complicated formula (that we will omit for this reason) and reported as a percentage. Remember good amplifiers should have as small a distortion factor as possible – values of 0.01% are no longer regarded as witchcraft.

23.1 Class A amplifiers

As you already know – sine waves have a positive and a negative half-wave. Both parts have to pass through the amplifier undamaged and come out amplified. So why not put half the battery voltage at the "quiescent point" so that the output voltage always oscillates evenly up and down from the middle voltage. The working point A1 marked in Fig. 264 fulfils this condition. An extended family of characteristic lines, where this is also true, is given in Fig. 338. Apart from the values given in Fig. 264, the base current, collector current and collector voltage for sine wave operation are also included.

If you study Fig. 338 you will be able to read it like a picture book. For instance you will see that even when the transistor is not receiving a signal (i.e. when the sine wave passes through zero), a current of ca. 15mA flows; this is the standing (or quiescent) current. Amplifiers of this type are known as **class A amplifiers**. At high currents they could be used as the heating for a medium-sized sitting room - the standing current alone consumes so much power that such amplifiers can only be employed at very modest wattages.



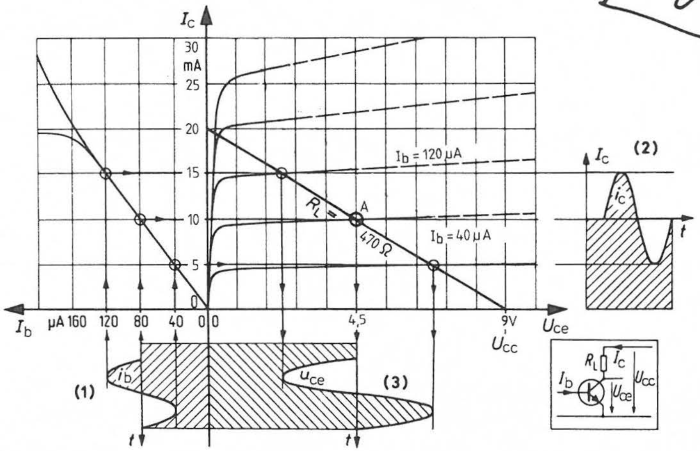


Fig. 338 Enlarged family of characteristic lines for a transistor; the behavior of the base current, the collector current and the collector voltage are also included.

23.2 Class AB push-pull amplifiers

The whole thing consumes a great deal less energy if we allow ourselves the luxury of a complementary transistor and divide the work of the amplifier between two transistors. Figure 339 shows the principle. The positive half-waves are only amplified by the n-p-n transistor which becomes conducting when the base becomes positive; the negative half-wave is only amplified by the p-n-p transistor, which becomes conducting as the base is negative. The two half-waves that have been amplified on a "push-pull" basis are reunitied as the emitters converge.

In the case of the class B push-pull amplifier a collecter current only flows when a half-wave is actually being amplified; without input both transistors are nonconducting. This only works in theory if value is placed on good reproduction qualities. Because the characteristic is displaced in the region of low base currents the half-waves do not completely complement each other after amplification. Because of this a little collector current is allowed to flow trough each transistor even in the absence of a signal, this is known as a **class AB push-pull amplifier**. Figure 341 shows a very simple and easily understood record player amplifier with an initial class A transistor stage and a class AB push-pull final stage; Fig. 340 shows the construction. It should be noted that, in the case of the first stage, the quiescent point is adjusted by means of a resistor between the base and the collector. This common type of circuit ("negative feedback") has the advantage of having a very high temperature stability at the quiescent point.

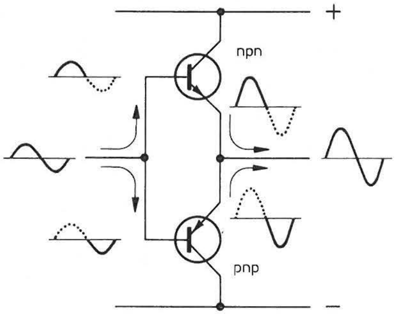
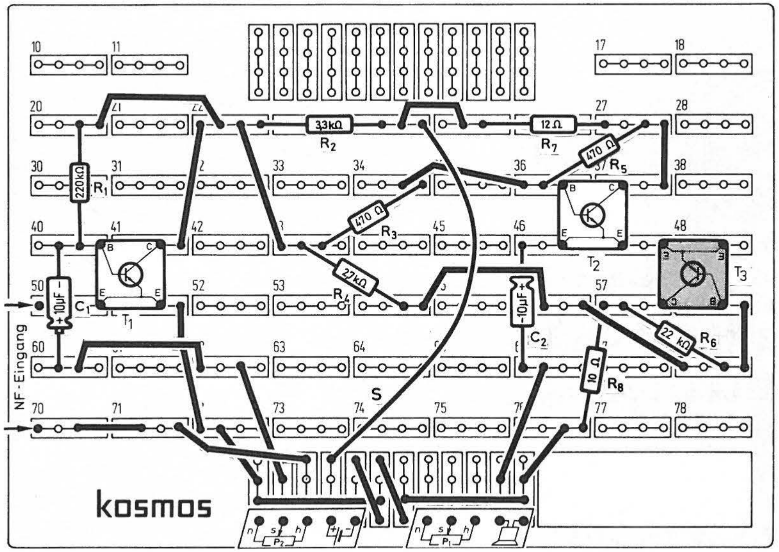


Fig. 339 Voltage-time curves in push-pull amplifier


10
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28
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31
33
34
36
38
40
41
42
45
46
48
50
52
53
57
60
63
64
70
71
73
74
75
77
78
33kΩ
R₂
12 Ω
R₇
470 Ω
R₅
220kΩ
R₁
470 Ω
R₃
27kΩ
R₄
22 kΩ
R₆
10 Ω
R₈
10µF
C₁
10µF
C₂
B
C
E
T₁
T₂
T₃
S
NF-Eingang
kosmos
P₁
P₂

Fig. 340 Construction of circuit 341

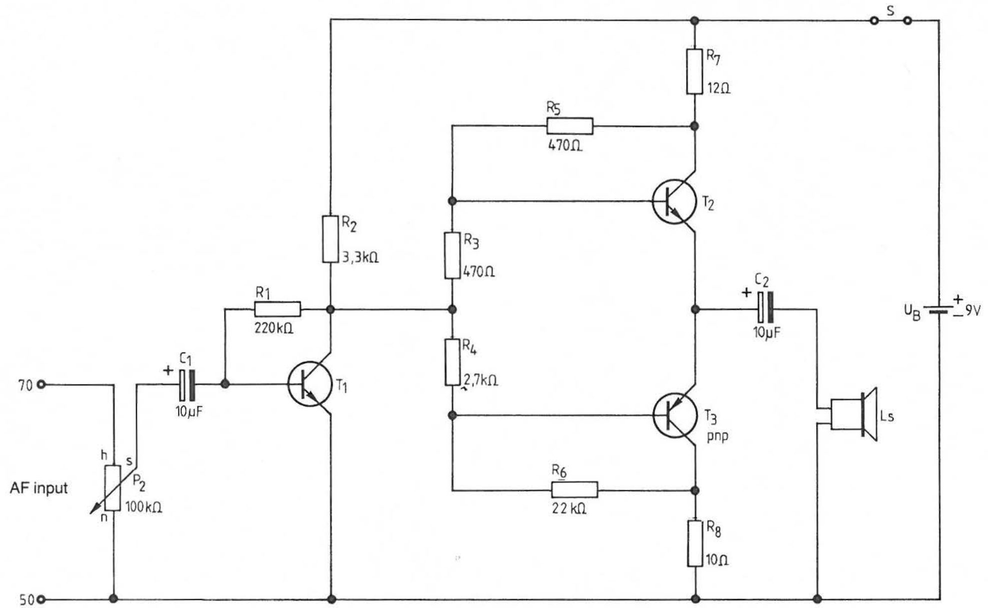

S
R7
12Ω
R5
470Ω
T2
R2
3,3kΩ
R3
470Ω
C2
+
10μF
U_B
+
9V
R1
220kΩ
C1
+
10μF
T1
R4
2,7kΩ
T3
pnp
Ls
70
AF input
h
s
P2
100kΩ
n
R6
22 kΩ
R8
10Ω
50

Fig. 341 Record player amplifier with class AB push-pull final stage

23.3 Class C amplifiers

This third type of amplifier, the class C amplifier, is only included for completeness. Here the idea of the class B amplifier is developed, but a further step is taken and the standing current is so depressed that only the upper and lower portions of a sine curve are amplified. This can be desirable for certain applications.

23.4 Comparison of circuits

A transistor is said to be emitter, collector or base-connected depending on which connection of a transistor is laid at the ground of the circuit (Fig. 342). The properties of the transistor are quite different from circuit type to circuit type; the most important data for practical purposes are given in Table 7.

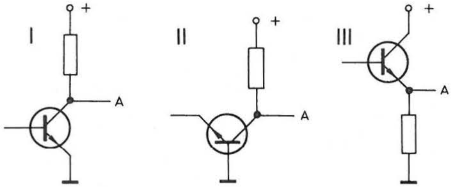


Fig. 342 Basic transistor circuits

Table 7 Properties of the basic transistor circuits

curcuit	input resistance	output resistance	voltage gain
I common emitter connection	medium (ca. 50kΩ)	medium (ca. 50kΩ)	big
II common base connection	very small	very big	very big
III common collector connection (emitter follower)	very big (depends on load resistor)	very small (ca. 50kΩ)	smaller or equal to 1

24. Mixed circuits

"Anyone who brings a great deal is bound to bring something" says the poet (Goethe, Faust) and here we have tried to represent the most important areas of electronics in as varied a manner as possible. It might be said that everyone, who can work with the components and circuits we have presented, is "a professional". This means that the aim of this experiment book has been reached. To round off we are going to present a few colorful circuits which we hope the newly fledged electronics professionals will enjoy.

24.1 Electronic chirrups

Electronic birds have a big advantage, they are easy to care for, require neither a cage nor bird seed and do not fly away if the window is accidentally left open.
Figure 343 shows the construction, Fig. 344 the circuit diagram of an electronic bird chirruper. You will recognize two astable multivibrators each made up of two inverter gates and a third in the form of an operational amplifier. The three oscillations thus generated are so combined that a distinct bird chirrup is produced. Afterwards you can experiment with the layout as much as you

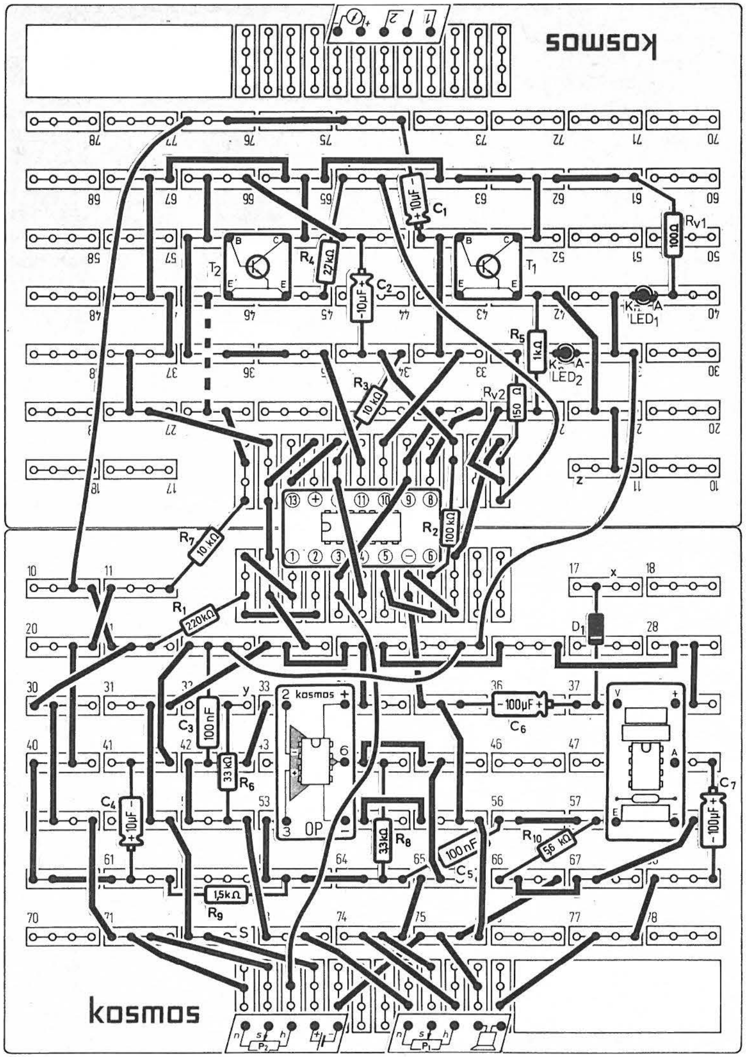

kosmos
T1
T2
C1 10µF
C2 10µF
R4 27kΩ
Rv1 100Ω
R5 1kΩ
LED1
LED2
Rv2 150Ω
R3 10kΩ
R2 100kΩ
R7 10kΩ
R1 220kΩ
D1
C3 100nF
R6 33kΩ
C6 100µF
C4 10µF
OP
R8 33kΩ
C5 100nF
R10 56kΩ
C7 100µF
R9 1,5kΩ
P1
P2
kosmos

Fig. 343 Construction of circuit 344

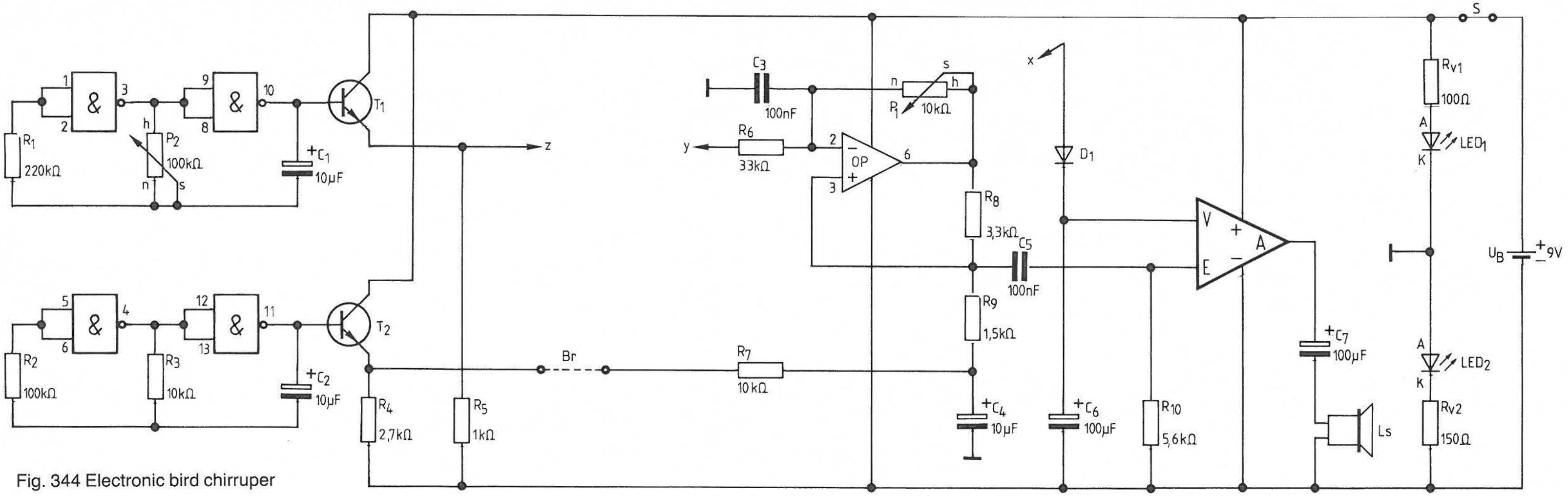

1
2
3
&
9
8
10
&
T1
R1
220kΩ
h
P2
100kΩ
n
s
+C1
10µF
z
5
6
4
&
12
13
11
&
T2
R2
100kΩ
R3
10kΩ
+C2
10µF
R4
2,7kΩ
R5
1kΩ
Br
R7
10kΩ
C3
100nF
s
n
h
P1
10kΩ
y
R6
33kΩ
2
3
OP
6
R8
3,3kΩ
C5
100nF
R9
1,5kΩ
+C4
10µF
x
D1
+C6
100µF
V
+
A
E
−
R10
5,6kΩ
+C7
100µF
Ls
S
Rv1
100Ω
A
LED1
K
UB
+9V
A
LED2
K
Rv2
150Ω

Fig. 344 Electronic bird chirruper

like in order to affect the pitch of the basic note and the noise of the chirrup.

Suggestions for experiments:

1. Remove wire connector Br; a constant note should be heard.
2. Replace the wire connector, the bird begins to trill; the note can be adjusted by turning P1.
3. Make a connection between z and y by means of a long piece of wire; the trill will become a chirrup.
4. Remove the long wire from y and put it in x instead; the chirrup will change.
5. Replace diode D1 by a wire connector.
6. P2 can also be adjusted in order to vary the chirruping during all the previous experiments.

24.2 Voltage frequency converter

In Section 21 we discussed the difference between analogue and digital inputs in detail and you will remember that a digital computer can only process the states "potential" or "no potential" (0 or 1; high or low). If you wish to use a computer to measure a particular voltage then this (analogue) voltage first has to be converted to a digital signal. One way of doing this is to employ a voltage frequency converter; a frequency in the form of a square wave (which periodically changes from low to high) can be processed by a computer if it counts the number of impulses in a fixed time and then displays the result. All that is required of the voltage frequency converter is that the input voltage and the output frequency are proportional to each other.

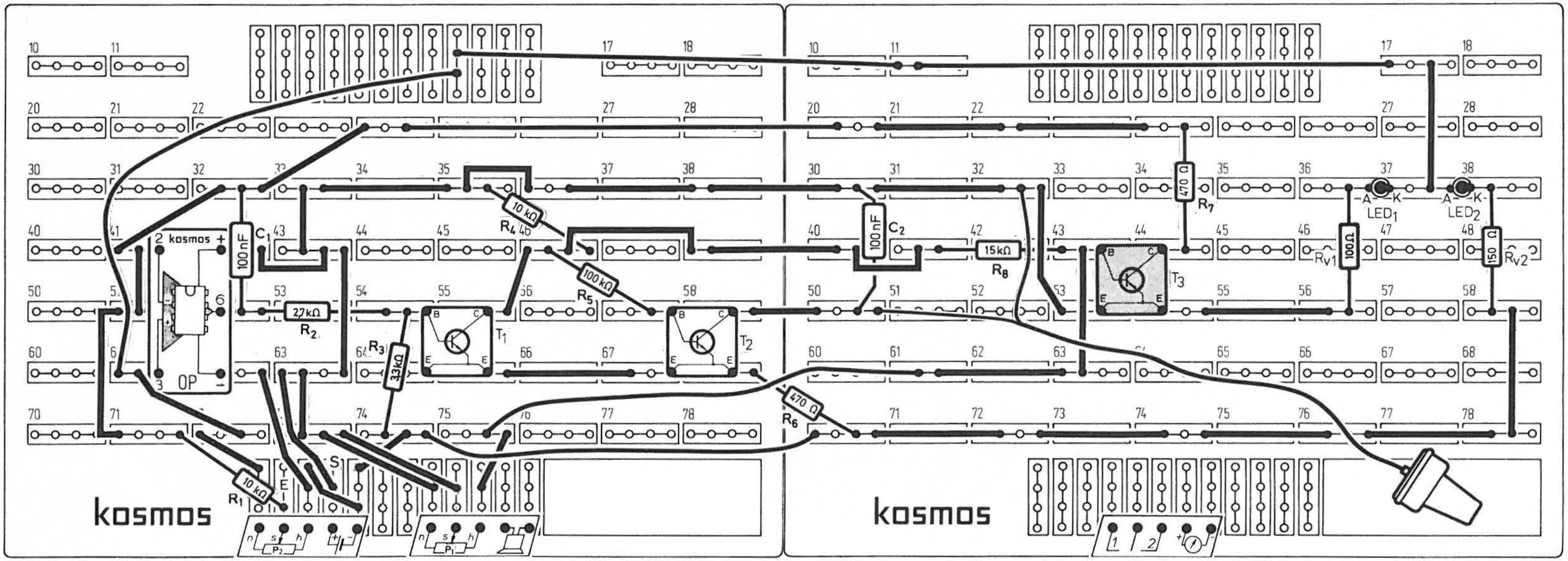

kosmos
kosmos
2 kosmos +
OP
100 nF
C1
2,7kΩ
R2
33kΩ
R3
10 kΩ
R4
100 kΩ
R5
470 Ω
R6
10 kΩ
R1
T1
T2
T3
100 nF
C2
15kΩ
R8
470 Ω
R7
LED1
LED2
100Ω
Rv1
150 Ω
Rv2
A
K
B
C
E
S
P1
P2

Fig. 345 Construction of circuit 346

The principle of circuit 346 is basically very simple. When a negative (!) input voltage is applied the output voltage of the operational amplifier integrator rises slowly. When a certain voltage is reached the Schmitt trigger of T1 and T2 reacts and triggers. This makes T3 conduct and switches the positive battery voltage onto the input of the integrator. Its output now falls very rapidly, until the Schmitt trigger switches back (its hysteresis behavior is very important in this context!). T3 thus becomes nonconducting once more and the integration process can begin all over again. The higher the input voltage the more rapidly the integration takes place, hence the higher the frequency that is produced. It is worth pointing out once more that the positive pole of the voltage to be converted is connected to the circuit ground and its negative pole must be at the input of the converter. In order to bring the construction according to Fig. 345 into service attach a "measurement voltage" to input E via the potentiometer slide of P2, turn P2 completely to the right and adjust P1 so that a high note can be heard in the earphone. This note changes to a lower pitch when P2 is slowly turned to the left.

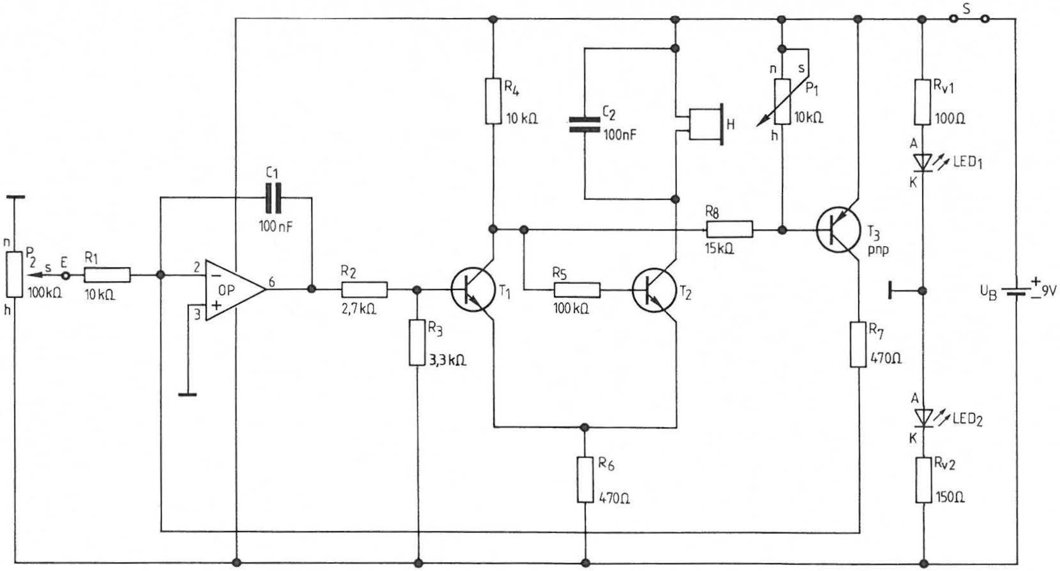
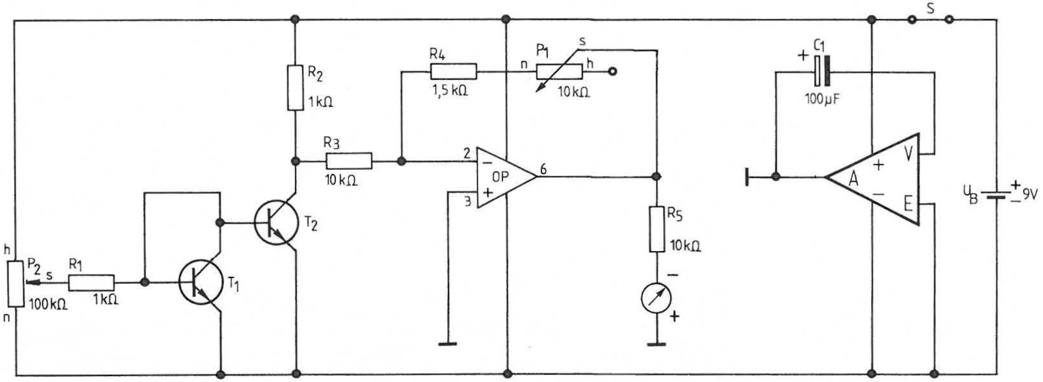

S
R4
10 kΩ
C2
100nF
H
n
s
P1
10kΩ
h
Rv1
100Ω
A
LED1
K
C1
100 nF
R8
15kΩ
T3
pnp
n
P2
s
E
R1
100kΩ
10kΩ
h
2
OP
6
3
R2
2,7kΩ
T1
R5
100kΩ
T2
UB
+
9V
R3
3,3kΩ
R7
470Ω
A
LED2
K
R6
470Ω
Rv2
150Ω

Fig. 346 Voltage frequency converter

24.3 Electronic thermometer

We are now going to discuss a circuit that converts temperatures to voltages that can then be displayed on your meter.
Figure 347 shows the construction, Fig. 348 the circuit diagram, in whose left-hand half we recognize the famous current compensation circuit made up of transistors T1 and T2. The voltage changes produced at the collector of T2 by changes of temperature are applied to the operational amplifier in inverting configuration, which amplifies or weakens them according to the position of P1.

Fig. 348 Electronic thermometer


S
R2
1kΩ
R4
1,5kΩ
n
P1
s
h
10kΩ
+
C1
100µF
R3
10kΩ
2
OP
6
3
V
A
+
−
E
UB
+
9V
T2
T1
h
P2
s
R1
100kΩ
1kΩ
n
R5
10kΩ
−
+

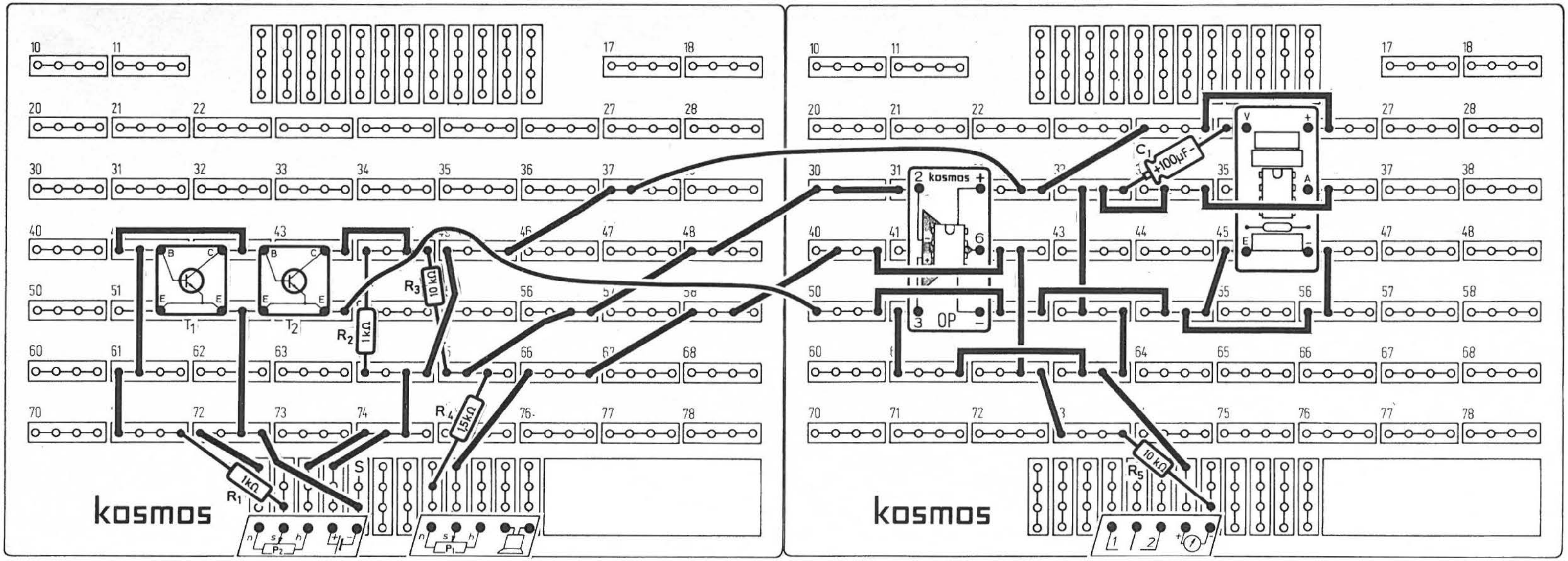


Fig. 347 Construction of circuit 348

thermometer for calibration. The principle is always the same, after setting the zero the temperature is then produced which it is intended shall result in a full-scale deflection of the meter (read off from the thermometer) and P1 is then adjusted so that the meter really does have a full-scale deflection.

Operation of the thermometer. First adjust the zero point by placing T1 in ice water at zero degrees Celsius (see Section 11.15) and then turn P2 until the meter reads zero. P1 can now be used to choose the "scale" (e.g. 1 scale division = 1 degree Celsius). It is entirely up to you how much effort you put into using a very accurate

24.4 From phase displacement generator to amplitude modulation

Capacitors transmit alternating current – that has already been discussed in Section 12.1. What has been ignored until now is that because of their ability to delay they displace the phase of the alternating current. This means that the passage of the current through zero is delayed by a quarter of a phase after an ideal capacitor (this amounts to 90 degrees) as compared with the situation before the capacitor. Figure 349 shows what is meant by this. Of course there are no ideal capacitors, in reality the phase displacement is always less then 90 degrees on account of the capacitor losses.

In order to induce a single transistor to oscillate it is necessary to phase displace its output by about 180 degrees and feed it into the base. If ideal capacitors were available then two of them would be able to accomplish this, in practice three are necessary, each of them causing a phase displacement of 60 degrees. The capacitors *C*1, *C*2

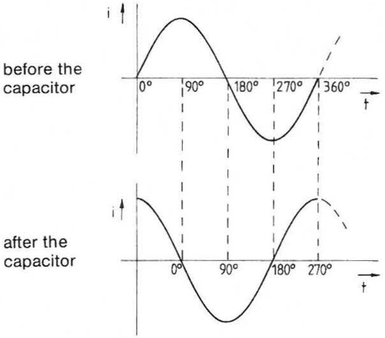
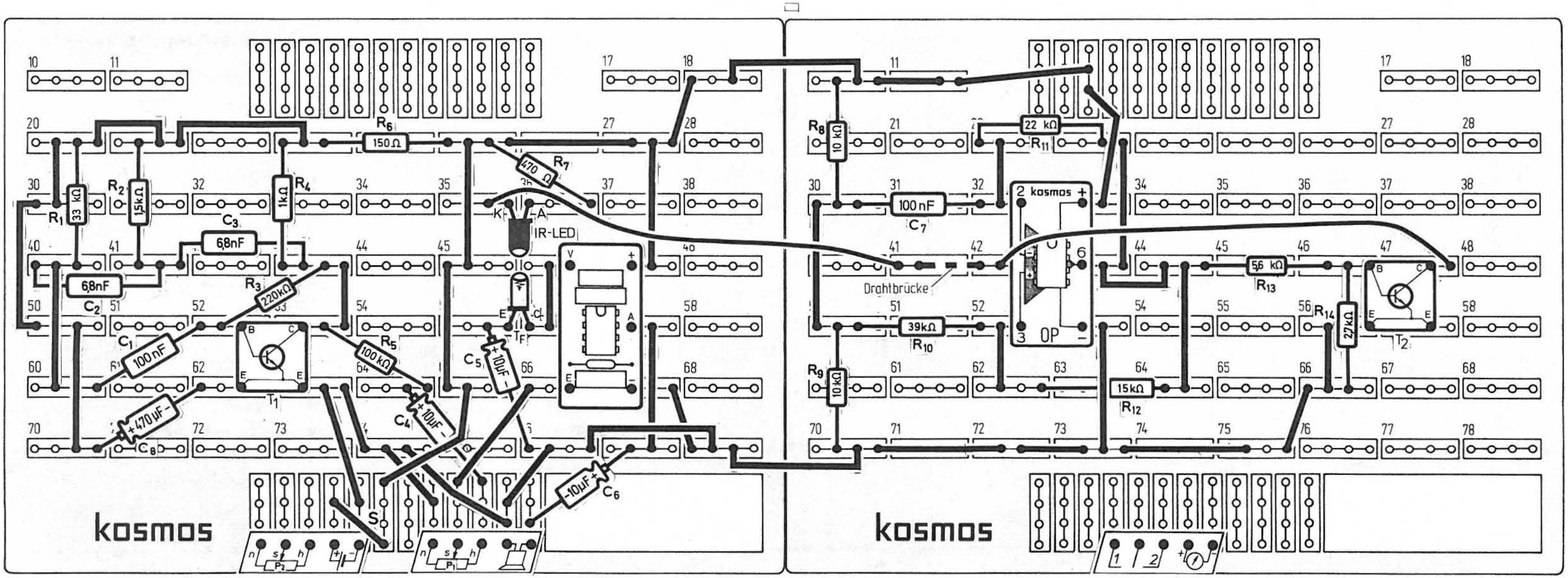


Fig. 349 Phase displacement at the capacitor

Fig. 350 Construction of circuit 351


R1 33 kΩ
R2 1,5kΩ
R4 1kΩ
R6 150 Ω
R7 470 Ω
C3 6,8nF
C2 6,8nF
R3 220kΩ
C1 100nF
C8 470µF
T1
B C E
R5 100kΩ
C4 10µF
C5 10µF
C6 10µF
K A
IR-LED
TF
S
P2
P1
kosmos
R8 10 kΩ
R9 10 kΩ
C7 100 nF
R11 22 kΩ
R10 39kΩ
kosmos OP
Drahtbrücke
R12 15kΩ
R13 5,6 kΩ
R14 27kΩ
T2
kosmos

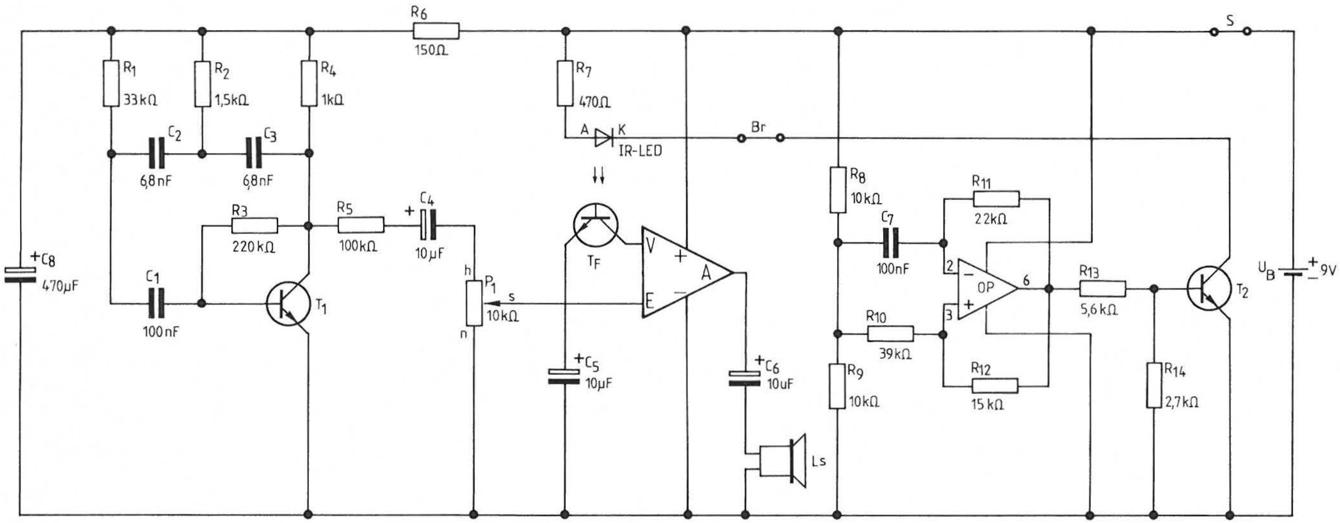

R6
150Ω
S
R1
33kΩ
R2
1,5kΩ
R4
1kΩ
R7
470Ω
C2
6,8nF
C3
6,8nF
A
K
IR-LED
Br
R8
10kΩ
R11
22kΩ
C7
100nF
R3
220kΩ
R5
100kΩ
C4
10μF
TF
V
A
E
+C8
470μF
C1
100nF
T1
h
P1
s
10kΩ
n
+C5
10μF
+C6
10uF
Ls
OP
2
3
6
R10
39kΩ
R9
10kΩ
R12
15kΩ
R13
5,6kΩ
R14
2,7kΩ
T2
UB
+9V

Fig. 351 Production of a sine wave potential with a phase displacement generator with following amplitude modulation

The operational amplifier on the right in circuit diagram 351 works as a square wave generator, the transistor connected after it produces sufficient current for the IR diode which is switched on and off periodically, when wire connector Br is plugged in. The amplification of the amplification module is switched at the frequency of the square wave generator, large and small amplitudes periodically appear at the output – what you have produced with this little circuit is a perfect amplitude modulation! (See Fig. 352.) If you listen carefully you can recognize both the high sine note and the humming of the square wave frequency. Take out wire connector Br and play the light of a pocket flashlight on the region of the phototransistor. You will be able to “adjust“ the loudness by means of the flashlight. Insert the wire connector Br and replace the 0.1μF capacitor *C7* with one of 1μF (positive side to OP AMP). The humming noise will turn into a “twittering“ caused by the change from loud to quiet notes.

and *C3* in circuit diagram 351 do just that and this is a construction that produces sine waves for us. The circuit is known as a **phase displacement generator**. As long as wire connector Br is not inserted in construction 350, it produces a relatively high, quiet note. The loudness is determined by the brightness of illumination of the phototransistor which is employed here in the role of a variable resistor; nonconducting transistor (little light) means low amplification, conducting transistor (a lot of light) means high amplification (and all intermediate states are also possible of course).

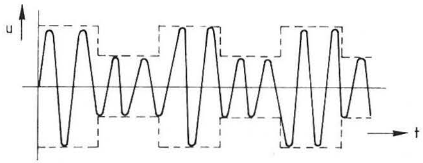
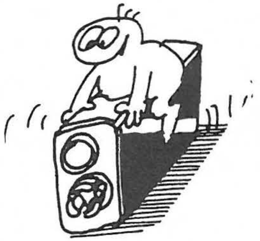


Fig. 352 Voltage-time diagram of the amplitude-modulated voltage

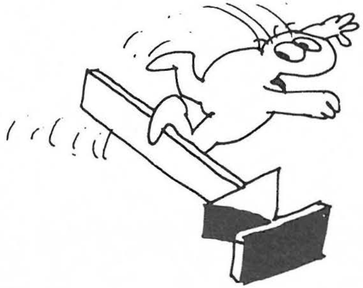
25. Fault finding

When a circuit does not want to perform, it is usually because of a mistake in its construction. The circuits themselves operate perfectly and have all been set up successfully on many occasions. When a problem occurs we suggest that you work through the following checklist.

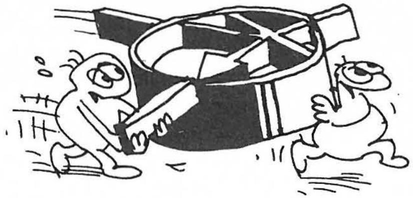
1. First check that the battery is not flat.



2. Check that the diodes, LEDs and electrolytic capacitors have been inserted with the right polarity.



3. Check that the transistors have been fitted the right way round.



4. The following resistors are easy to mix up: 10Ω (brown-black-black), 100Ω (brown-black-brown), 1kΩ (brown-black-red), 10kΩ (brown-black-orange), 100kΩ (brown-black-yellow) and 1MΩ (brown-black-green) and 3.3kΩ (orange-orange-red) and 33kΩ (orange-orange-orange) as are 150Ω (brown-green-brown) and 15kΩ (brown-green-orange) and possibly even 1.2Ω (brown-red-gold) and 12Ω (brown-red-black).

5. Are all the wire connectors properly fitted? It is best to cross off on the component diagram each part that is inserted. Further check that the contact clip holes are occupied or unoccupied as they are in the construction diagram.

6. You can check whether a component is dud by building the circuit in which it was first employed, if there is no test circuit for it (e.g. the transistors in Figs. 64 to 69).

7. Some components may have connecting wires that are somewhat too long and need shortening. Otherwise they stick out of the bottom of the contact clips and may touch each other, which can lead to unwanted short circuits.

8. Are the modules with the ICs properly fitted? A wrongly fitted IC could be supplied with the wrong polarity supply voltage and become hot and break down.

9. The insulation of the connecting wires should never be inserted in the holes of the contact clips (no contact!).

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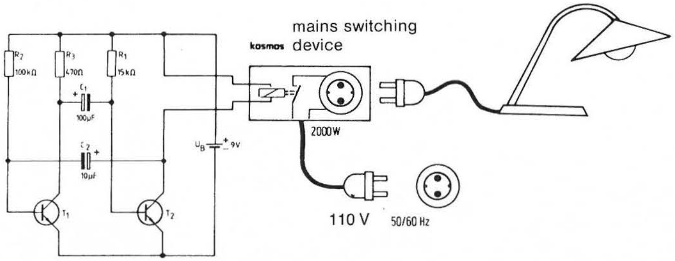

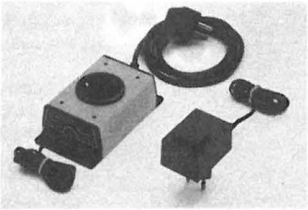

Farbe	colour	Couleur	1. Ring (1. Ziffer) 1st ring (1st figure) 1ère bague (1er chiffre)	2. Ring (2. Ziffer) 2nd ring (2nd figure) 2ère bague (2ème chiffre)	3. Ring (Zahl d. Nullen) 3rd ring number of noughts 3ère bague (Nombre de zeros)	4. Ring (Toleranz) 4th ring (tolerance) 4ème bague (Tolèrance)
schwarz	black	noir	0	0	—	—
braun	brown	brun	1	1	0	± 1%
rot	red	rouge	2	2	00	± 2%
orange	orange	orange	3	3	000	
gelb	yellow	jaune	4	4	0000	
grün	green	vert	5	5	00000	
blau	blue	bleu	6	6	000000	
violett	violet	violet	7	7		
grau	grey	gris	8	8		
weiß	white	blanc	9	9		
ohne Ring	without ring	sans bague				± 20%
Manchmal auch:	sometimes also:	Parfois aussi:				
gold	gold	or			× 0,1	± 5%
silber	silver	argent			× 0,01	± 10%

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